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HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

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Paper 868 HW 1

JOURNAL

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

ANALYSIS OF A SKEW DIVERSION

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(Proc. Paper 868)

SYNOPSIS

When a roadway intersects a relatively straight and stable stream at an acute angle, a common way of diversion is a skew culvert with or without reduction of skew. When the culvert is put at a reduced skew, a ditch parallel to the roadway is often used. By the principles of engineering economics, the most economical location of the culvert can be obtained, taking into account the economic, hydraulic and topographical factors involved. The result of this analysis shows the relative importance of these factors, and can be used as a guide to economical design of skew diversions.

INTRODUCTION

When a roadway intersects a stream at an acute angle, there are several possible alignments for the culvert. It may be put along the stream-bed, or put at a reduced skew with a diversion ditch. The choice among these alignments must be made by considering the total cost, including costs of construction, maintenance and depreciation, and flood damages. This problem has been previously discussed qualitatively by engineers in practice.(1,2) From an inspection of field conditions and a review of literature, the California Division of Highways recommended that small skews should be eliminated, moderate skews retained, and large skews reduced.(2) When a large skew is encountered in the field, the present practice is to compare the total costs of several trial alignments chosen according to the experience of the engineer. In this paper, the various factors that must be taken into account are enumerated in greater details, and a type of skew diversion, as shown schematically in Fig. 1, is chosen for analysis. The main purpose of this paper is to find the relative importance of the economic, hydraulic and topographical factors involved. The results of the analysis will serve as guide to determine (a) the amount of skew that should not be reduced, and (b) the proper amount of reduction if reduction is warranted.

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In this paper, only relatively straight streams are considered. In the case of meandering streams, so many variables are involved as to make a simple solution unattainable. The problem involving meandering streams has been discussed in Reference 2. The arrangement shown in Fig. 1 is chosen for study because it is usually the best solution for relatively straight and stable streams. However, in rare cases, other arrangements may be better, and should be investigated and compared with this arrangement. In such cases, the economical solution presented in this paper will serve as a basis of comparison.

A roadway intersecting a relatively straight stream at an acute angle is shown in Fig. 1. Angle A is the angle of skew of the stream. The culvert may be put along the stream-bed or at a reduced skew angle B. While the length of the culvert is reduced by reducing the skew, there are many additional costs and hazards involved in skew reduction. A partial list of these involves (a) cost of construction, cost of land, and maintenance of the ditch; (b) cost of bank protection, especially at the bends; (c) sedimentation in the ditch and the culvert, especially when the latter is a multiple-cell structure; and (d) possible adverse effects to the regime of the stream below. In the case of moderate skews, the reduction in cost of the culvert barrel is not enough to compensate the additional costs and hazards due to skew reduction. On the other hand, when the skew is large and the culvert is large and long, the reduction in the cost of the culvert may be great enough to warrant a reduction of skew.

Costs and Flood Damages

Since the costs of diversion must be considered in this analysis, a brief discussion of costs is appropriate here. It should be pointed out that many of the costs are difficult to determine, but they must be taken into account although they can only be roughly estimated in practice. In the present practice in business and engineering, the total cost of a structure is considered to consist of several items: first cost, maintenance cost and depreciation (operating cost being nil in this case). If no salvage is allowed for the structure at the end of its service life, the total annual cost can be expressed as[3]

$$\text{Total annual cost} = Ir + If + M \qquad (1)$$

in which I = total first cost installed,
r = current annual rate of bank interest, written as a decimal,
f = annual depreciation rate, usually computed by the sinking fund formula: $f = r/(1+r)^{n-1}$, where n is the service life of the structure in years,
M = annual maintenance charge.

In finding the relative economy of alternative designs of a drainage structure, their performance, in terms of flood damages, must also be considered. Let D be the average annual flood damages (in dollars) with the structure installed. The total annual cost and damages can then be expressed as

$$\text{Total annual cost and damages} = I(r+f) + M + D \qquad (2)$$

By flood damages is meant the sum of losses due to damage done to the

structure itself, flooding of upstream properties, loss of use of the highway, erosion of the downstream channel, etc. When a drainage structure is properly designed for a given flood, only floods with larger discharge will cause damages. A method of computing D, the average annual flood damages, can be found in a book by Barrows.(4) It suffices to say here that, to compute the average annual flood damages, the frequency-peak discharge data of the stream and the stage-damages data of the locality are needed.

The use of Eq. 2 in economic study depends on the purpose of the study. For example, when the problem is to decide what kind of material is to be used for the culvert to pass a design discharge, the average annual flood damages may be considered to be the same for all the proposed materials, and the comparison can be made by considering only their costs, as given by Eq. 1. Another problem is the choice of the design flood. If the culvert is designed for a small and frequent flood, the first cost will be small but the average annual flood damages will be large. On the other hand, if the culvert is designed for a larger and less frequent flood, the average annual flood damages will be small but the first cost will be large. The most economical design flood to use is one which gives the minimum total costs and damages, as given in Eq. 2. Since the economical design discharge depends mainly on the relative values of the first cost and the flood damages, it can be seen that, for utmost economy, different parts of the structure should be designed for different discharges. For example, headwalls and wingwalls can be designed for a flood larger and less frequent than the design discharge for the culvert barrel. The reduction of damages to the embankment due to these less frequent floods may be more than enough to compensate for the slight increase of the first cost. In short, different parts of the drainage structure should, theoretically, be designed for different design discharges which depend on the local hydrological conditions, the value of the near-by properties, the importance of the highway, etc. However, since the determination of the flood damages in each individual case is difficult and time consuming and, at best, approximate, the present culvert practice is to adopt some standard frequencies of flood for design. An example of such standards for design is that used in California where the culvert barrel is designed to pass a 10-year flood without surcharge and the appurtenances designed for a 100-year flood.(2) The determination of the design frequencies for various parts of the drainage structure is outside the scope of this paper. In this paper, it is considered that the design discharges for the culvert barrel, the diversion ditch and other appurtenances have been fixed. It suffices to say that, due to the relatively heavier damages to the diversion ditch at large discharges, the design discharge for the ditch should generally be larger than that for the culvert barrel. As the term "design flood" implies, the culvert size is to be so chosen that no damage is done to the upstream area due to ponding during the design flood of the barrel. The ditch should be of such size and the bends should be so protected that, during the design flood of the ditch, no damage is done to the ditch as well as to the channel downstream.

The problem to be treated in this paper is as follows: Given the type of culvert to be used, and given the design discharges for the barrel and for the ditch, find the most economical alignment and grade for the culvert by using Eq. 2. Let the subscripts o, 1, and 2 indicate quantities pertaining to the culvert along the stream-bed, the culvert at a reduced skew, and the diversion ditch, respectively. Let I_a be the first cost of culvert appurtenances, I_b be that of bank protection at the bends, and I_f be that for filling the stream when

the culvert is not put along the stream. Eq. 2 can then be rewritten, for a culvert along the stream-bed, as

$$\text{Total annual cost and damages} = I_o(r+f) + I_a(r+f) + M_o + D_o \qquad (3)$$

and, for a culvert with a given reduction of skew, as

$$\text{Total annual cost and damages} = I_1(r+f) + I_2 r + I_a(r+f) + I_b r + I_f r + M_1 + M_2 + D_1 + D_2 \qquad (4)$$

The problem is to find the value of angle B and the value of culvert grade s_1 for the minimum value of Eq. 4, and compare this minimum value with that of Eq. 3. No reduction of skew should be made unless the minimum value of Eq. 4 is less than that of Eq. 3.

The first costs I_o and I_1 of the culvert barrels include such cost items as materials and transportation, excavation (borrow, in the case of I_o) and backfill, bed preparation, placing of structure, and others. A discussion of this subject can be found in Reference 2 (pp. 137-168). When the culvert is not put along the stream, there is an additional cost I_f for filling the stream under the road. I_o and I_1 do not include the cost I_a of the appurtenances. The cost I_a for a given job may vary slightly with the alignment due to the difference in direction of the headwall, etc. relative to the culvert. This minor difference in cost is small compared to the total cost of diversion, and, for simplicity without introducing serious error, is ignored in the following analysis; that is, I_a is considered to be the same in Eq. 3 as in Eq. 4.

The cost I_2 of the ditch depends on the size of the ditch, the type of soil, revetment, if any, along the ditch, cost of land, and other local conditions. Only those costs that increase with the length of the ditch are included in I_2. The cost I_b of bank protection at the three bends is practically independent of the length of the ditch, and is considered as a separate item. Since the ditch is a permanent feature if properly maintained, no depreciation is allowed for it.

The maintenance cost for the culvert depends on the type of culvert used. For a given case, M_o and M_1 may be considered to be proportional to the length of the culverts, unless there is trouble of sedimentation created by reduction of skew. Since sedimentation inside the culvert must be avoided, not only to reduce the maintenance cost, but also to avoid reduction of culvert capacity due to probable delay of cleaning the culvert in time of flood, multiple-cell structures should be used with skew reduction only when experience or experiment shows that there will be no trouble of sedimentation. The maintenance cost M_2 for the ditch varies from case to case, depending on whether there are problems of silting and vegetation. When there is backwater from the downstream channel during low flow through the culvert, silting may be a serious problem.

Flood damages may occur in different forms. Damages may be done to the upstream properties by ponding, to the culvert itself by erosion of embankment and to the channel downstream by bank cutting. In the case of diversion with a reduction of skew of the culvert, there may be damages done to the ditch and additional damages to the downstream channel created by the

change in direction of flow at the last bend. For comparative study, D_o and D_1, in Eqs. 3 and 4 respectively, may be considered to be the damages done to the upstream side of the structure. If the ditch is so designed that the culvert outlet is not submerged during the design flood of the ditch (which is generally larger than the design flood of the culvert), the depth of ponding upstream of the culvert with reduced skew will not be much different from the depth for the culvert along the stream. The difference (D_1-D_o) is then mainly due to floods larger than the design flood of the ditch. The quantity D_2 may be considered to be the sum of the damages done to the ditch and that part of the damages done to the downstream channel due to the change of direction of flow at the last bend. Needless to say, the determination of (D_1-D_o) and D_2 is difficult. Perhaps the best the engineer can do is to make his judgment according to the value of the properties and the nature of the stream at the culvert site. This difficulty is common to all methods of analysis, such as the conventional trial-and-error method, and the analytical method used in this paper.

It is not the purpose of this paper to make a detail analysis of the costs of culverts. This brief discussion on costs is given to form a basis for the analysis to be presented presently. When the analytical results are applied to particular cases, the accuracy of the result depends on how exactly these costs can be ascertained. This fact points to the need of further study of these costs, especially the flood damages. Such information is important not only in this problem of culvert location, but also in problems of culvert economy in general, such as the determination of economical design flood frequency for each class of road and near-by environment.

Economic Study of Culvert Location

Reduction of skew for the culvert is warranted only when the total cost and damages computed from Eq. 3 for the case of no reduction is greater than that computed from Eq. 4 for a skew reduction. In other words, skew reduction should be made only when

$$T_o > T_1 + T_2 + T_r \tag{5}$$

in which

$$T_o = I_o\left(1 + \frac{f}{r}\right) + \frac{M_o}{r} \tag{5a}$$

$$T_1 = I_1\left(1 + \frac{f}{r}\right) + \frac{M_1}{r} \tag{5b}$$

$$T_2 = I_2 + \frac{M_2}{r} \tag{5c}$$

and

$$T_r = I_f + I_b + \frac{(D_1-D_o)+D_2}{r} \tag{5d}$$

T_o, T_1, and T_2 are the total capitalized costs for the culvert put along the stream-bed, the culvert at a reduced skew, and the ditch respectively. By

total capitalized cost is meant the sum of the first cost and the amount of money which interest will pay for perpetual maintenance and renewal of the structure at the end of the service life. T_r is the total capitalized incidental costs and additional flood damages due to skew reduction. It is the sum of the cost of filling the stream, the cost of bank protection at the bends, and the amount of money which interest will make good, on the average, all future additional flood damages created by skew reduction.

If the local conditions are such that Eq. 5 is true, skew reduction should then be considered. The best skew angle B for the culvert and the best grade s_2 for the ditch are those which together give the lowest value of Eq. 4. This skew angle and grade combination can be obtained by partially differentiating Eq. 4 with respect to B and s_2, and setting the partial derivatives to zero. In Eq. 4, I_a, I_b, I_f and D_1 have been shown to be practically independent of the values of B and s_2. Since D_2 is difficult to ascertain in practice, it is assumed to be independent of the values of B and s_2. In other words, D_2 is assumed to be independent of the length of the ditch. This is more or less equivalent to the assumption that the damages of the ditch are small compared to those of the bends and the downstream channel. With this assumption, the value of angle B and ditch grade s_2 for minimum value of total cost obtained from Eq. 4 are given by the following two simultaneous equations:

$$\frac{\partial}{\partial B}(T_1 + T_2) = 0 \tag{6}$$

and

$$\frac{\partial}{\partial s_2}(T_1 + T_2) = 0 \tag{7}$$

In many cases, the best grade s_2 can be ascertained by simple reasoning, as will be shown subsequently. The best angle B is then given by

$$\frac{d}{dB}(T_1 + T_2) = 0 \tag{8}$$

Eqs. 5 to 8 are to be used in the following sections for economic study of culvert location. Several cases are considered with different hydraulic and topographical conditions. In each case, the culvert is designed to pass its design flood without raising the depth of ponding over a specified limit. The ditch is designed to discharge its design flood with a depth not over a certain limit: (a) When the ditch is on the downstream side of the culvert and there is no backwater from the channel downstream, the water surface in the ditch during its design flood should not be over the crown of the culvert outlet; (b) When the ditch is on the downstream side of the culvert and there is backwater from the channel downstream, the submergence of the culvert outlet during the design flood of the ditch should not be greater than that of the culvert without skew reduction; and (c) When the ditch is on the upstream side of the culvert, the depth of flow in the ditch during its design flood should not be over the depth of ponding created by the same discharge for a culvert without skew reduction. With the ditch designed in this manner, there is practically no increase of ponding and therefore no additional flood damages to the upstream area due to skew reduction up to the design discharge of the ditch.

Thus (D_1-D_o) is mainly due to floods larger than the design flood of the ditch.

Case 1: Primarily for earth ditch with level ditch site

In order to avoid erosion in the ditch during its design flood, the velocity of flow must be kept below an allowable limit. When the ditch is not lined, the allowable velocity depends mainly on the type of soil and is generally very low.(5) This being the case, the bottom slope of the ditch must be very gentle. It follows that the required size of the culvert will change only slightly, if at all, with the amount of skew reduction. The required size of the culvert along the stream-bed can be determined in the usual manner and will serve as the approximate size of culvert required for skew reduction. Since the allowable ditch velocity and the depth of flow are known for the design flood of the ditch, the required ditch section and the bottom slope can be determined. (Required water cross-sectional area = Q/v; with depth of flow and this area, determine required width of ditch; compute hydraulic radius of section, and determine bottom slope with Manning's formula). If the existing ground is level at the ditch site, the depth and width of excavation are uniform along the ditch. For this case, the total capitalized cost per unit length of ditch C_2 $(= T_2/L_2)$ is uniform along the ditch and is independent of the skew angle B. The value of

$$C_2 = \frac{T_2}{L_2} \tag{9}$$

for a given case can be computed from the required ditch section, estimated unit cost of construction and maintenance charge.

In Fig. 2 is shown schematically the variation of total cost and damages with skew reduction. The total cost T_2 of the ditch increases while the total cost T_1 of the culvert decreases with the amount of skew reduction. There is a step-change in T_1 when there is a change of the required size of the culvert. From this figure, several qualitative conclusions can be drawn: (a) The minimum total cost and damages is obtained from one of two alternative alignments: along the stream-bed, or at the optimum alternative alignment indicated in the figure. Skew reduction is warranted only when the latter proves to be more economical than the former. (b) When skew reduction is warranted, the amount of reduction is not very critical. One can use a value of angle B several degrees from the optimum value without increasing materially the total cost of the structure. Thus, if there is an existing structure or a side-road in the way of the optimum alternative alignment, these obstacles may be avoided by using a slightly larger value of B. (c) A lower total cost may be obtained at the point where there is a decrease of the required culvert size. Since the change of the required culvert size with skew is small in this case, this special case can be ignored.

Let

$$C_o = \frac{T_o}{L_o} \tag{10}$$

and

$$C_1 = \frac{T_1}{L_1} \tag{11}$$

in which C_o and C_1 are the total capitalized cost per unit length of culvert along the stream-bed and near the optimum alternative alignment respectively. C_1 in general is approximately equal to C_o. The value C_o can be found since the size required for the culvert along the stream-bed can be determined. The optimum alternative alignment can be obtained from Eq. 8:

$$\frac{d}{dB}(T_1+T_2) = \frac{d}{dB}(C_1L_1 + C_2L_2)$$
$$= \frac{d}{dB}\left[C_1L_o\cos A.\sec B + C_2L_o(\sin A - \cos A.\tan B)\right]=0 \tag{11a}$$

or

$$\sin B = \frac{C_2}{C_1} \cong \frac{C_2}{C_o} \tag{12}$$

This value of angle B gives the best alternative alignment and should be used only when skew reduction is proved to be warranted. From Eq. 5, skew reduction is warranted only when

$$T_o = C_oL_o > C_1L_1 + C_2L_2 + T_r \tag{12a}$$

For practical purpose, use the approximation $C_o = C_1$. Then

$$\frac{T_r}{T_o} < 1 - \cos A.\sec B - \frac{C_2}{C_o}(\sin A - \cos A.\tan B) \tag{13}$$

Eq. 13 is plotted with solid lines in Fig. 3 with the value of angle B obtained from Eq. 12. In practice, compute C_2, C_o and T_o as indicated above, and estimate the value of T_r. From Fig. 3, find allowable T_r. If the allowable T_r is greater than the estimated T_r, the difference indicates the saving of skew reduction. When there is a significant saving, the optimum alternative alignment given by the solid lines in Fig. 4 (plotted according to Eq. 12) should be considered.

The solution for this case has been obtained by assuming that the velocity in the ditch during its design discharge is equal to the maximum allowable velocity. In some rare cases with extremely flat stream-bed and soil of coarse materials, this solution may lead to a culvert with level or adverse slope. In such rare cases, the culvert should be put at the minimum allowable slope and use the solution of Case 3.

Case 2: Primarily for earth ditch with sloping ditch site

This case is the same as Case 1 except that the existing ground is not level. Although the water cross-section of the ditch is uniform along the

ditch as in the previous case, the cost per unit length of ditch is no longer uniform along the ditch. While T_0 and T_1 can be expressed as Eqs. 10 and 11, T_2 cannot be represented by Eq. 9 with a constant C_2 in this case. Instead let, for analytic purpose,

$$T_2 = k\, L_2^N \tag{14}$$

in which, for a given case, k and N can be determined by computing T_2 for two or more lengths of ditch. Thus the optimum alternative alignment can be obtained from Eq. 8:

$$\frac{d}{dB}(T_1+T_2) = \frac{d}{dB}(C_1L_1 + k\,L_2^N)$$
$$= \frac{d}{dB}\left[C_1L_o\cos A.\sec B + kL_o^N(\sin A-\cos A.\tan B)^N\right]=0 \tag{14a}$$

or

$$\frac{\sin B}{N(1-\cot A.\tan B)^{N-1}} = \frac{C_2'}{C_1} \cong \frac{C_2'}{C_0} \tag{15}$$

in which

$$C_2' = k(L_0\sin A)^{N-1} \tag{15a}$$

is the average total capitalized cost per unit length of the ditch that would be required for total elimination of skew (i.e. if angle B = 0). If N=1 as in the case of level ditch site, Eq. 15 is reduced to Eq. 12 of Case 1, since C_2' will then become the same as C_2. Eq. 15 is plotted with dashed line in Fig. 4 with N = 2. The value of N in practical cases usually falls between 1 and 2. Fig. 4 can be used for intermediate values of N by interpolation.

The value of B obtained from Fig. 4 or Eq. 15 should be used only when reduction of skew is warranted. According to Eq. 5, skew reduction is warranted only when

$$T_0 = C_0L_0 > C_1L_0\cos A.\sec B + kL_0^N(\sin A-\cos A.\tan B)^N + T_r \tag{15b}$$

For practical purpose, use the approximation C_o=C_1. Then the condition for skew reduction is

$$\frac{T_r}{T_0} < 1 - \cos A.\sec B - \frac{C_2'}{C_0}\sin A(1-\cot A.\tan B)^N \tag{16}$$

With the value of angle B from Eq. 15, Eq. 16 is plotted with dashed lines in Fig. 3 for N=2. Note that the solutions for N=1 and N=2 are practically the same for the usual low values of C_2'/C_0.

In practice, determine the required size of the culvert along the

stream-bed and compute T_o and C_o. Determine the required ditch section and bottom slope as in Case 1. Compute the total capitalized cost of the ditch that would be required for skew elimination (i.e. if angle B = 0), and divide this cost by $L_o \sin A$ to obtain C_2'. Estimate the values of N and T_r. If the estimated T_r is less than the allowable T_r from Fig. 3 by a significant amount, the optimum alternative alignment obtained from Fig. 4 should be considered. Otherwise, no skew reduction should be made.

Case 3: Primarily for paved ditch at level site, with culvert designed with hydraulic control at entrance

Since the first cost of a paved ditch is necessarily higher than an unpaved one, paving can be economical only when the total drop of the stream bottom $s_o L_o$ is large, so that a small paved ditch can be used with high velocity of flow. When the culvert is designed with hydraulic control at the entrance, the required size is independent of the alignment as long as the culvert is put at the critical slope. In this case, therefore, put the culvert at the critical slope to produce critical flow in the culvert. For cases where paving is warranted, the required drop of the culvert invert $s_1 L_1$ for critical flow is small compared to the total drop $s_o L_o$ of the stream. Thus the drop of the ditch bottom $s_2 L_2 (= s_o L_o - s_1 L_1)$ can be approximated by $s_o L_o$.

$$s_2 \cong \frac{L_o}{L_2} s_o \tag{17}$$

While the total drop of the ditch bottom is known, the ditch grade s_2 varies with the skew of the culvert. For convenience, let C_2'' be the total capitalized cost per unit length of the ditch section that would be required to pass the design flood with a bottom slope equal to s_o of the stream (Since the depth of ditch flow for its design discharge is known, the width of ditch that would be required can be determined from Manning's formula). The capitalized cost per unit length C_2 for ditch at any slope s_2 can then be expressed as

$$C_2 = C_2'' \left(\frac{s_o}{s_2}\right)^m \tag{18}$$

where m depends on the shape of the ditch section, the ratio of the depth of flow to the depth of excavation, and other factors. The value of m usually falls between 0.1 and 0.3. It will be shown that the exact value of m is not necessary for the solution of this problem in practice. Combining Eqs. 17 and 18,

$$C_2 = C_2'' \left(\frac{L_2}{L_o}\right)^m \tag{19}$$

Thus, from Eq. 8, the optimum alternative alignment is given by

$$\frac{d}{d\beta}\left[C_1 L_o \cos A . \sec B + C_2''\left(\frac{L_2}{L_o}\right)^m L_o (\sin A - \cos A . \tan B)\right] = 0 \tag{19a}$$

or

$$\frac{\sin B}{(1+m)(\sin A-\cos A.\tan B)^m} = \frac{C_2''}{C_1} \cong \frac{C_2''}{C_0} \qquad (20)$$

Eq. 20 is plotted as Fig. 6 for m = 0.1 and m = 0.3. Note that the exact value of m is not necessary for practical purpose. Also note the similarity between Figs. 4 and 6.

The alternative alignment given by Eq. 20 should be used only when reduction of skew is warranted. According to Eq. 5, skew reduction should be made only under the following condition:

$$\frac{T_r}{T_0} < 1 - \cos A.\sec B - \frac{C_2''}{C_0}(\sin A - \cos A.\tan B)^{1+m} \qquad (21)$$

With the value of angle B from Eq. 20, Eq. 21 is plotted as Fig. 5. Note the similarity between Fig. 3 and Fig. 5.

The solution in this case has been obtained by assuming that the allowable velocity in the ditch is not reached. In rare cases the velocity in the ditch according to this solution may become too high to be desirable. Such cases have been considered under Case 1 where the velocity in the ditch controls the design. The solution of Case 1 should be used.

Case 4: Primarily for paved ditch at level site with culvert designed to flow full

In this case, the required size of the culvert and that of the ditch depend on the choice of bottom slope as well as the alignment. Let C_2'' be defined as in Case 3. The total cost T_2 of the ditch at any slope s_2 is then, according to Eq. 18,

$$T_2 = C_2'' \left(\frac{s_0}{s_2}\right)^m L_0(\sin A-\cos A.\tan B) \qquad (22)$$

To compute the cost of the culvert, it is necessary to find how its size and its cost per unit length change with angle B and s_2 used. When the culvert is flowing full, the required size is determined by the following formula as long as the outlet is not submerged over the crown but may be submerged up to the crown.

$$H + sL - d = \frac{Q^2}{2gA^2}\left(1 + K_e + f\frac{L}{d}\right) \qquad (23)$$

where H is the allowable ponding depth above the invert at the entrance, and d is the vertical dimension of the culvert. Eq. 23 can be approximated by

$$\frac{d}{H+sL} = G\left[\frac{L}{(H+sL)^{4/3}}\right]^{0.173}\left[\frac{Q}{(H+sL)^{5/2}}\right]^{0.83} \qquad (24)$$

where G depends on the shape of the culvert section and the surface roughness. For the culvert along the stream-bed, $L = L_o$ and $sL = s_oL_o$. For the culvert at a reduced skew, $L = L_1 = L_o\cos A.\sec B$ and $sL = s_1L_1 = s_oL_o - s_2L_2 = s_oL_o - s_2L_o(\sin A - \cos A.\tan B)$. According to Eq. 24, the required sizes d_o and d_1 for these two cases are related:

$$\frac{d_1}{d_o} = \frac{(\cos A.\sec B)^{0.173}}{\left[1 - \frac{s_2L_o}{H+s_oL_o}(\sin A - \cos A.\tan B)\right]^{0.306}} \tag{25}$$

The size d_1 can be quite different from d_o in this case. For analytic purpose, assume that the cost of culvert is a continuous function of the required size, as expressed by the following expression:

$$\frac{C_1}{C_o} = \left(\frac{d_1}{d_o}\right)^j \tag{26}$$

The value of j may vary between zero and unity. Thus the capitalized total cost T_1 for the culvert at a reduced skew is

$$T_1 = C_1L_1 = C_oL_o\frac{(\cos A.\sec B)^{1+0.173j}}{\left[1 - \frac{s_2L_o}{H+s_oL_o}(\sin A - \cos A.\tan B)\right]^{0.306j}} \tag{27}$$

For convenience of discussion, two cases, with j = 0 and j = 1 respectively, are considered:

a) j = 0 in Eq. 26:

With the value of T_1 from Eq. 27 and T_2 from Eq. 23, Eqs. 6 and 7 show that the ditch should be put at as steep a grade as possible, and the optimum alternative alignment is the same as that given by Eq. 20 in Case 3. Thus Figs. 5 and 6 can be used for this case, with the culvert grade s_1 kept at the minimum allowable value.

b) j = 1 in Eq. 26:

Since the exact value of m in Eq. 22 is not important as shown in Case 3, the following solution is obtained with m = 3/16. With the value of T_1 from Eq. 27 and T_2 from Eq. 22, Eqs. 6 and 7 give the following two simultaneous equations for the optimum alternative alignment and the ditch grade:

$$\frac{s_2}{s_o} = 0.662\left(\frac{C''_2}{C_o}\right)^{16/19}\left(\frac{\cos B}{\cos A}\right)^{0.988}\left(\frac{H+s_1L_1}{H+s_oL_o}\right)^{1.10} \tag{28}$$

and

$$\sin B\left(\frac{\cos B}{\cos A}\right)^{0.012} = 1.09\left(\frac{H+s_1L_1}{H+s_oL_o}\right)^{0.10}\left[\frac{C''_2}{C_o}\left(\frac{s_oL_o}{H+s_oL_o}\right)^{3/16}\right]^{16/19} \tag{29}$$

Although the angles A and B may vary from a few degrees to 80^o in practice,

the value of $(\cos B/\cos A)^{0.012}$ varies only from 0.98 to 1. For practical purpose,

$$\sin B = 1.09\left(\frac{H+s_1L_1}{H+s_0L_0}\right)^{0.1}\left[\frac{C_2''}{C_0}\left(\frac{s_0L_0}{H+s_0L_0}\right)^{3/16}\right]^{16/19} \tag{30}$$

Dividing Eq. 28 with Eq. 29 and simplifying,

$$\frac{H+s_1L_1}{H+s_0L_0} = \frac{1}{1+0.605\ \sin B.\cos B(\tan A-\tan B)} \tag{31}$$

The solutions for the optimum alternative angle B and the culvert grade s_1 from Eqs. 30 and 31 are shown graphically in Fig. 7. The grade of the ditch is then given by

$$s_2L_2 = s_0L_0 - s_1L_1 \tag{32}$$

In cases with the value j between zero and unity, the optimum alternative angle and culvert grade s_1 will be in between those for the two cases considered. Usually the value of j is closer to unity and Fig. 7 will give a fair solution. In some rare cases, Fig. 7 may give a solution that would require a culvert with an adverse grade. In such cases, the culvert should be put at the minimum allowable grade, and Figs. 5 and 6 should be used.

It should be emphasized again that the optimum alternative alignment thus obtained should be used only when it gives lower total cost and damages than an alignment along the stream-bed, as indicated by Eq. 5.

Case 5: Small skew

In the previous cases, it has been assumed that, if skew reduction is made, a diversion ditch is necessary for the completion of the diversion. However, if the skew of the stream is so small and the stream-bed is so wide that a culvert perpendicular to the roadway can be put within the stream-bed, no diversion ditch is necessary. In such cases, the skew may be completely eliminated (angle B = 0) if the flow from the outlet would not cut the bank near-by.

This conclusion may also be arrived at from the solutions presented previously. Consider that the required T_r is zero and that the cost per unit length of an imaginary ditch is zero, any of the solutions presented above indicates that the best alignment for the culvert is one with angle B=0.

SUMMARY

In the choice of alignment for skew culverts, the total cost (including first cost, maintenance and depreciation) and flood damages must be considered.

The result of this analysis substantiates the California practice, and gives a more quantitative differentiation between "large" and "moderate" skews. Skew reduction should be considered only for cases where Eq. 5 is true

(Estimated T_r, as defined by Eq. 5d, is less than allowable T_r given by Figs. 3 and 5). Chief conditions in favor of skew reduction are large skew of the stream, wide roadway, large culvert, less expensive properties at the culvert site, and stable stream-bed.

When skew reduction is justified, there is an optimum amount of reduction (see Figs. 4, 6 and 7). This optimum position is not very critical. The culvert may be put a few degrees away from the optimum position to suit local conditions (to avoid side-roads, existing structures, etc.). There is also an optimum grade for the ditch and one for the culvert (see Case 4). However, in most cases, the optimum grade is obvious (see Cases 1, 2, 3 and 4a).

In spite of the fact that different hydraulic controls and topographical conditions are considered, the solutions are roughly the same (compare Figs. 3 and 5, and Figs. 4 and 6). The important factors are the relative costs per unit length of the ditch and culvert, the skew angle A of the stream and the required T_r/T_o. Since in practice the required T_r can only be roughly estimated and the optimum alternative alignment is not very critical, satisfactory solutions can be obtained even when the costs C_2 of the ditch, etc. can only be approximately ascertained. The graphs presented in this paper may be used for direct solution for the location of skew culverts; or, if the conventional trial-and-error method of solution is preferred, these graphs will suggest values of angle B and grade for trial solution.

NOTATION

The following symbols are listed for the convenience of reference. Other symbols used have been defined where they first appear. The subscripts o, 1, and 2 are used to designate quantities pertaining to the culvert along the stream-bed, the culvert at a reduced skew, and the diversion ditch, respectively.

A = skew of stream (see Fig. 1), except in Eq. 23 where A is the cross-sectional area of culvert.

B = skew of culvert (see Fig. 1).

C_o = T_o per unit length of culvert.

C_2 = T_2 per unit length of ditch.

C_2' = average total capitalized cost per unit length of ditch if angle B equals to zero (see Case 2).

C_2'' = total capitalized cost per unit length of ditch that would be required if s_2 is equal to s_o (see Case 3).

(D_1-D_o) in Eq. 5d = additional annual flood damages to upstream area caused by skew reduction.

D_2 in Eq. 5d = additional annual flood damages to ditch and downstream channel caused by skew reduction.

f = annual depreciation rate (see Eq. 1), except in Eq. 23 where f denotes the friction coefficient.

H = allowable depth of ponding above invert of culvert entrance.

I = first cost.

I_b = first cost of bank protection at bends.

I_f = first cost of filling the stream under roadway.

L = length of culvert or ditch.

M = annual maintenance charge.

m = exponent in Eq. 18.

N = exponent in Eq. 14.

r = annual rate of interest.

s = bottom slope.

T_o = total capitalized cost of culvert along stream-bed (see Eq. 5a).

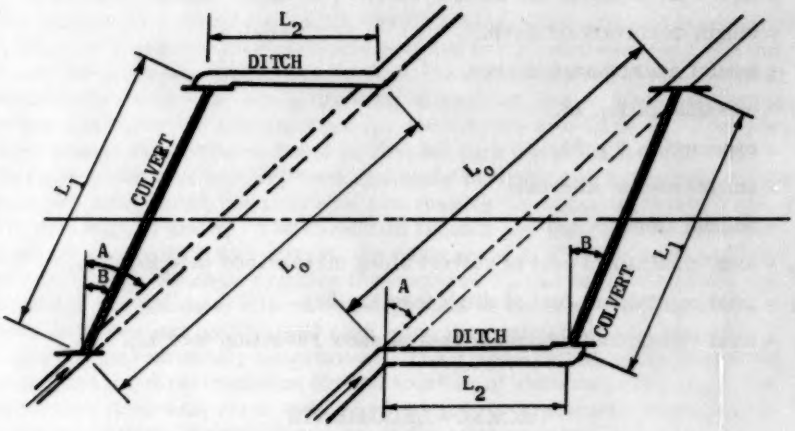
T_2 = total capitalized cost of ditch (see Eq. 5c).

T_r = total capitalized incidental cost of skew reduction (see Eq. 5d).

ACKNOWLEDGMENTS

The State Roads Commission of Maryland is the sponsor of this study as a part of a research project at the Civil Engineering Department of The Johns Hopkins University. Professor J. Trueman Thompson, Chairman of the Department, is the Director of the research project.

The author is indebted to Mr. Robinson R. Rowe, Research Bridge Engineer of the California Division of Highways, who offered constructive criticism and called attention to several important practical facts related to the problem. However, all the statements made and the analytical approach to the problem are the sole responsibility of the author.



$$L_1 = L_o \cos A . \sec B$$
$$L_2 = L_o (\sin A - \cos A . \tan B)$$

Fig. 1. Schematic Drawing Showing Culverts at Reduced Skew.

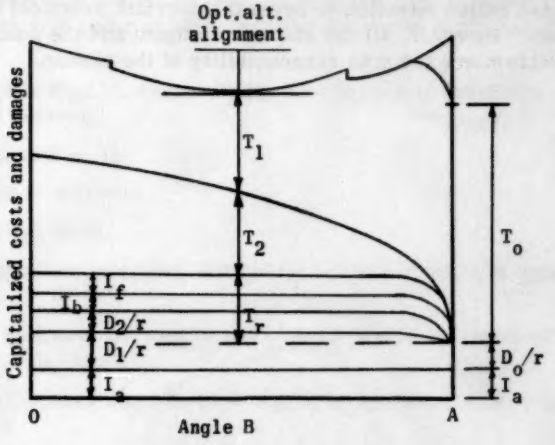


Fig. 2. Variation of Capitalized Costs and Damages with Skew Reduction.

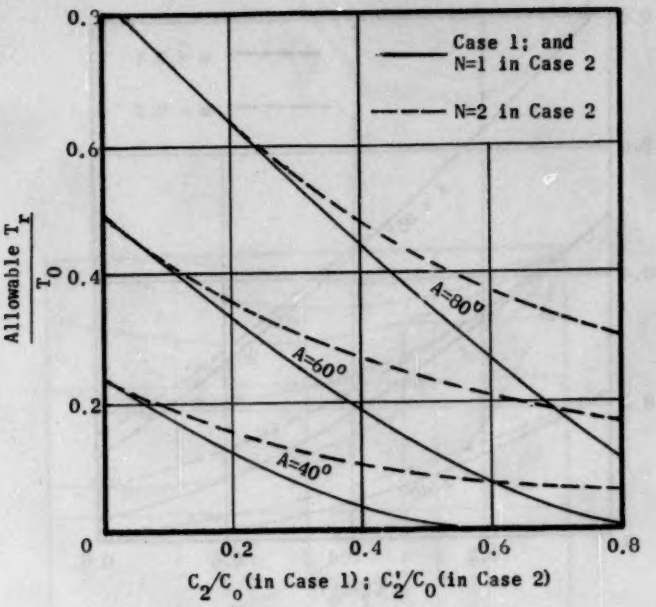


Fig. 3. Allowable T_r in Case 1 and Case 2.

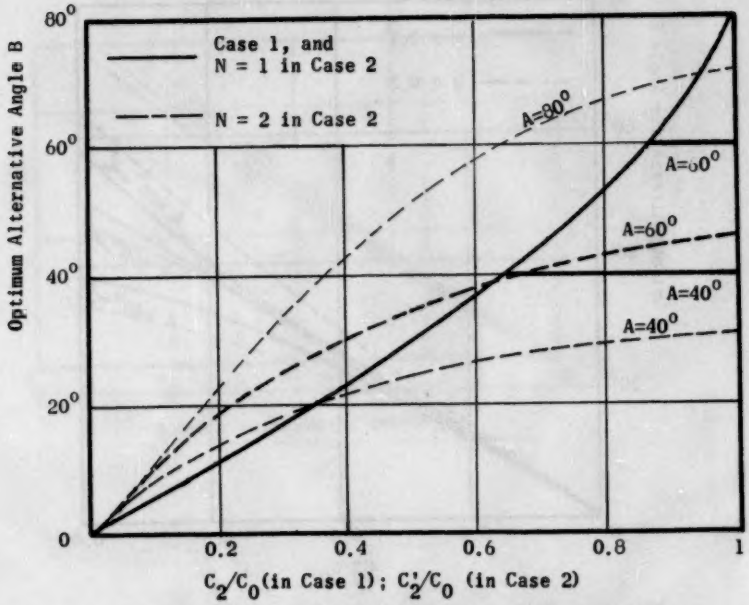


Fig. 4. Optimum Alternative Alignments for Case 1 and Case 2.
(to be used only when skew reduction is justified)

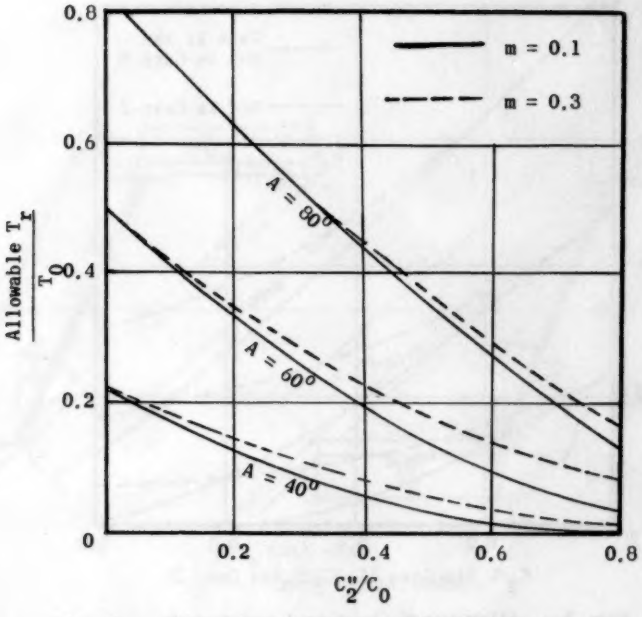


Fig. 5. Allowable T_r for Skew Reduction in Case 3.

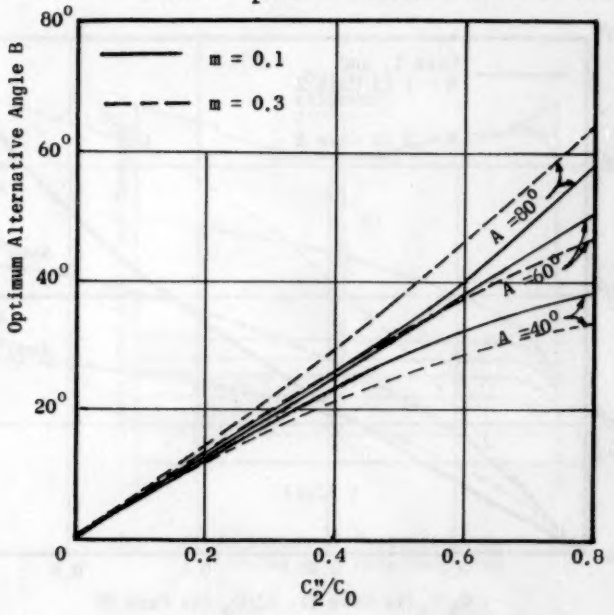


Fig. 6. Optimum Alternative Alignments for Case 3.
(to be used only when skew reduction is justified)

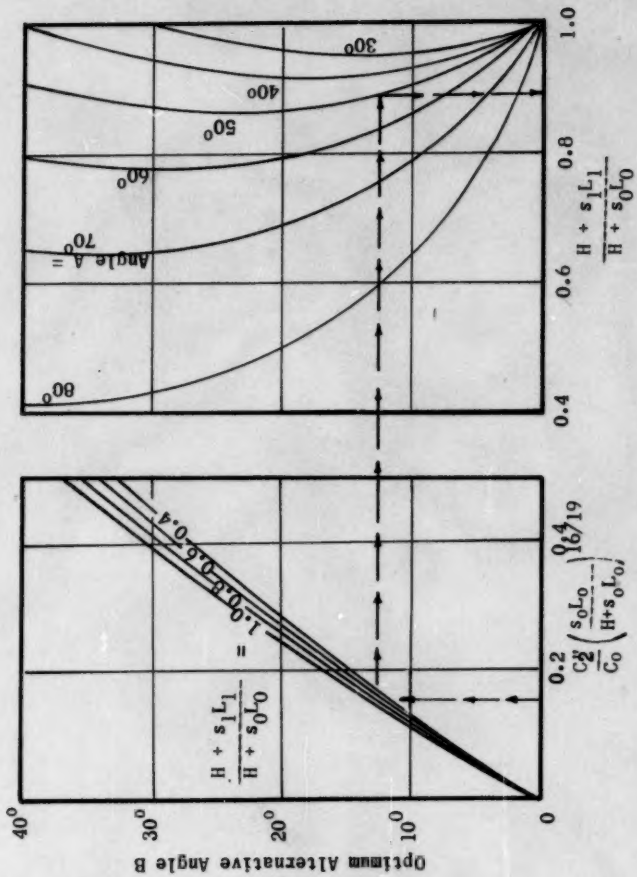


Fig. 7. Optimum Alternative Alignments and Grades for Case 4. (to be used only when skew reduction is justified)

JOURNAL

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

CONTROL OF HIGHWAY ACCESS: EXPERIENCES IN NEW YORK

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(Proc. Paper 871)

FOREWORD

The limitation or control of access to public highways is probably the major feature distinguishing modern highways from those built in earlier periods. True enough, the separation of grades at intersections, the dividing of highways to separate traffic moving in opposing directions and the provision for extra lanes to accommodate heavy traffic flows, are also embodied in the design of highways currently being constructed to provide for the ever-increasing numbers of moving motor vehicles. However, it is believed that the denial of abutters' rights to enter at will upon public highways is the fundamental change in the concept of a modern highway. This concept has been slow to evolve and a number of the American states do not yet have legal authority to construct highways which include access prohibitions. Other states have had such favorable acceptance of this principle, that they exercise access control whenever land is purchased for highway relocations. A few states go further and curtail roadside development by declaring certain existing highways to be freeways.

The purpose in arranging the Symposium was to broaden knowledge of the subject and to encourage greater use of this means of reducing the obsolescence of the highways needed for our motor vehicle economy.

SYNOPSIS

Experience with New York Thruway has shown how limited-access highways foster safety, save travel time, reduce wear and tear on vehicles and drivers, relieve traffic on parallel roads, and promote astounding economic development of area through which expressway runs. Conservative estimates credit Thruway for attracting at least $150,000,000 in new or expanded enterprises, with annual payroll in excess of $100,000,000. More superhighways needed across nation, but immediate problem is how to finance them.

Note: Discussion open until May 1, 1956. Paper 871 is part of the copyrighted Jour- of the Highway Division of the American Society of Civil Engineers, Vol. 82 No. HW 1, January, 1956.

1. Chairman, New York State Thruway Authority, Albany, N. Y.

One of the most intriguing subjects to occupy the attention of highway engineers in recent years is the necessity for control of highway access. Much of our discussion, however, has been largely theoretical because the mileage of modern, controlled access roads has been small indeed when compared with the total mileage of our various highway systems.

Despite this somewhat limited field of observation, we were able to arrive at some unassailable conclusions as to the desirability of access control. We found, for example, that limited access, divided highways foster safety, eliminate wasteful stop-and-go driving, save time and reduce wear and tear on the vehicle as well as the driver.

There are many other advantages of control of access which are known to all of us and have been the subject of discussions and papers over a period of many years. When I was asked to talk on the subject here, therefore, I thought a review of our experience in operating the world's longest controlled access highway might be of considerable interest to the members. The New York State Thruway has been in operation now for well over a year. It was not opened all at once, nor is it completed yet. But since the first toll opening in June, 1954, we have had a first-hand look at the actual effects the Thruway has exerted on the State's economy as well as on traffic operations.

Background

Before discussing these effects in detail, it is helpful to consider some of the factors which led to the construction of the Thruway and has made its operation so valuable to our State. New York is the most populous of the 48 States and is second only to California in the number of motor vehicle registrations. It has a diversified economy with a tremendous concentration of all types of industry, commerce and agriculture. It might surprise many of you, for example, to learn that New York ranks second among all the states in the production of milk and apples. It rands third in vegetable growing and sixth in hay production. On the other hand we have 50,000 manufacturing firms of all sizes and types plus a tourist business worth $2 billion annually.

I mention these facts because they add up to an acute traffic problem. Our motor vehicle registrations increased 25 per cent just between 1949 and 1954 while there was an even greater rise in their use. We have some 14,385 miles of State highway system, of which more than 8,000 miles are rated as less than tolerable. This, of course, is exclusive of the Thruway, which ties in with all of our principal routes and forms the trunk line for the swift movement of people and goods across the State.

The principal east-west routes are 5 and 20 and the north-south routes, 9 and 9-W. A great deal of work has been done on these main arteries over a long period of years. However, it became more and more obvious here as in other comparable states that no program of widening and reconstructing existing routes could ever accomplish the necessary traffic relief. Not only was the cost prohibitive, but it offered no permanent solution. On these principal routes, mushrooming roadside developments have increased to a point where the highways efficiently carried only a fraction of their original traffic capacity. Whatever safety features the highways originally had were dissipated in a blaze of multi-colored electric signs and accident-breeding marginal developments of every type and description. Nearly ten years ago the State embarked on a long-range program of planning and building a system of arterial routes in and adjacent to cities as a means of relieving urban

traffic problems. At the same time the Thruway was planned to link our two largest cities, New York and Buffalo, by way of Albany, Schenectady, Utica, Syracuse and Rochester.

The Thruway

In common with a number of other states, New York was forced to resort to toll financing to construct the Thruway. Today we have in operation 396 miles of the project, extending from Buffalo eastward to Albany and south to Suffern at the New Jersey line. This open section will be extended later this year across a three-mile Hudson River bridge and southward through Westchester County to the fringe of metropolitan New York.

As of now, motorists and truckers have traveled some 862,700,000 miles since the first section of the facility was opened to traffic. This has given us a solid basis for observing and analyzing the effects of limited access highways.

We have established, for example, that control of access reduces accidents, especially the deadlier kind. Our fatality rate is now 2.55 per 100 million vehicle miles, compared to the 1954 national average of 6.5 and a New York State average of 5.3. Moreover, not one of the fatal accidents was due in any way to the design or construction of the highway itself. Unfortunately, we do not yet have correctives for faulty judgment or the human tendency to err. Motorists and truckers traveled 96 million miles before our first fatal accident was recorded and we went through the long Memorial Day and July Fourth weekends without a fatality.

Of the hundreds of letters received by the Authority on the advantages of Thruway travel, those most commonly mentioned are freedom from irritation and fatigue and savings in driving time. Apparently the motorist places a good deal of value on the reduced nerve strain the Thruway offers. The motorists observed that they arrived at their destinations more relaxed and in better physical and mental condition than when they used the existing parallel highway system.

The speed of operation and savings in travel time were among the most frequently mentioned. Motorists can figure on traveling over the Thruway at the adopted speed limits; namely, 60 miles per hour for passenger cars and 50 miles per hour for all others. Except for time out for gas stops, rest and meals, these maximum speeds become the average speeds travelled. These rates are considerably in excess of the 30 to 45 miles per hour average covered when using the existing highway system.

Mr. William M. Baker, Manager of Manufacturing for General Electric's Electronics Division at Syracuse. says "The Thruway helps make economical a system of satellite plants." GE's operations have been set up so that the new expressway has become a modern connecting artery among its various plants, over which parts and assemblies are channeled. The firm's enthusiasm for the Thruway was solidified recently by a series of independent tests staged by General Electric's transportation experts to test the operating economies for its trucks on the Thruway.

On a round trip between Buffalo and its Schenectady plant, General Electric found that its trucks averaged 10.64 miles per hour better time on the Thruway than on parallel highways, saved 14.2 gallons of fuel, made 298 fewer gear shifts and 69 fewer full stops. Such statistics promise substantial savings in transportation costs for the company's large trucking operations.

One of the effects of a new limited access highway is the relief of traffic pressures on parallel routes. This has been demonstrated graphically in New York since the opening of the Thruway. On parallel Route 20, for example, traffic volume on a section south of Utica dropped 40 per cent in the first six months after the Thruway was completed in that area. Similar effects have been felt, although usually in lesser degree, along other sections of Route 20.

This siphoning of thru traffic from existing routes has not been viewed as a blessing in some quarters. Merchants and small enterprises along the older highways have complained of a sharp decline in business. Yet the Thruway is performing one of its basic functions, namely to relieve traffic on parallel routes and reduce the annual cost of maintaining them, thus making it possible for them to adequately handle local or regional traffic. This fact combined with the accessibility and the new economic climate of the region being brought about by the cross-State expressway is already replacing this business with new commerce, which is certain to exceed the lost business in a few years.

The Thruway's Economic Effects

As a matter of fact, by far the most amazing benefits of the Thruway observed to date have been exerted on the economy of the State as a whole.

During the planning stages and the construction period, the Authority was beset by contentions that loss of taxable property taken for Thruway purposes would impose a financial burden on the communities through which it ran.

It appeared certain to us, however, that this loss would be more than overcome by the increased value of the remaining property brought about by its accessibility to the Thruway. The Authority has been observing indications of this trend and has found that in every case where data are available, the increases have far exceeded the taxable losses. The greatest gains have been evident on property immediately adjacent to the Thruway interchanges, with lesser increases noted in rough proportion to the distance from the interchanges. This influence is radial and its extent is dependent on the accessibility to the Thruway by way of the existing road network.

While it is too early to assess the full impact of the Thruway on real estate values and while there is no formula for measuring its impact, I might give a few typical examples of the trend:

1) On the north side of the Thruway at one of the Syracuse interchanges, there is a piece of property containing 23 acres. No water, sewer or gas facilities are available. Before the Thruway was located in this area, the land was appraised at $100 per acre. Last March, this plot was sold to a machinery company for $46,000, or $2,000 per acre.
2) In Tarrytown, a local merchant who had originally paid $55,000 for a four-acre corner site near the Thruway several years ago, recently resold this property to an operator who plans a shopping center, for approximately twice that amount.
3) The Wall Street Journal some time ago made a detailed study of the effect of the Thruway on the State's economy. Among the findings were that a 21-acre piece of land along the Thruway in Syracuse sold for $15,000 in 1951 but that recently 12 1/2 acres of the same land went for $150,000. The survey revealed that land near the Thruway in the Buffalo area had jumped from a few hundred dollars an acre to $5,000 an acre.

4) The tiny upstate village of Fultonville (population 900) was bisected by the Thruway and created concern among the residents when the Thruway location was first accounced. However, after careful consideration of the benefits of the plan, the enlightened mayor and citizenry took a broader view. The results have been most satisfactory. The village now has a larger assessed valuation than before and has retired its village debt. Its tax rate has dropped from $33 per $1,000 of assessed value to $19 because of new enterprises.

It is not until we go into the matter of industrial growth along the Thruway that the full economic impact of controlled access highways is made evident. When a new state highway is built through undeveloped property, this undeveloped property experiences an increase in value because of its accessibility to the new facility. Almost overnight, it seems, the highway has attracted its complement of gasoline stations, restaurants, tourist cabins and other similar concession type developments.

While some of this same type of development is in evidence in the immediate vicinity of the Thruway interchanges, the commercial expansion has been dominated by the construction of industrial plants, both large and small.

In the relatively short time in which the Thruway has been under construction and in operation, it has been conservatively estimated that more than 150 million dollars' worth of new industrial plants have been erected adjacent to it. These plants are estimated to employ about 30,000 persons with an annual payroll in excess of 100 million dollars.

Perhaps the most vigorous growth attributable to the Thruway has been in the Syracuse area, where several huge new facilities, each costing many millions of dollars, have been erected. The vast new plants of General Electric Company's Electronics Park have direct access to the expressway. Fronting the Thruway is the recently completed 10-acre plating factory of the General Motors Corporation (Brown-Lipe-Chapin Division). Nearby are Carrier Corporation's latest air conditioning production unit; Allied Chemical and Dye Corporation's (Solvay Process Division) new chlorine and caustic-soda installations; Bristol Laboratories' just-finished plant for making pharmaceuticals; Western Electric Company's six-acre upstate service center.

One sector of Syracuse Industrial Park, a 1,000-acre district on the Thruway, is being filled by a dozen or more projects. These include steel-supply warehouses, storage and retail-chain depots, a bank, various offices, a radio-broadcasting concern and metals, machinery and other manufacturers.

Elsewhere in the State, leading firms, both large and small, have also been alert to Thruway potentials. In the Hudson Valley, for example, the superhighway was one element in International Business Machines Corporation's decision to erect its next giant factory near the Kingston interchange. It was also a factor inducing the Star Expansion Bolt Company to locate in Mountainville, in Orange County's dairy country. In the Mohawk Valley, the Beech-Nut Packing Company pointed to quick Thruway delivery to New York City when it announced an expansion at Canajoharie. In Westchester, the availability of a sizeable plot at the major interchange with the Cross County Parkway was a key reason for the location there of the newly opened, $30 million Cross County Center, one of the largest shopping centers in the country. The same pattern prevails all across the State and we are sure from the evidence at hand that this economic revolution has just begun. Modern expressways nourish every segment of the economy. They benefit agriculture, industry, commerce, labor, the tourist business, and give rise to an amazing variety of new enterprises.

The Future

These are some observations, however fragmentary, based on our relatively brief experience in the operation of the Thruway. I wish time would permit a fuller discussion of the products and by-products of our experience. It will be interesting in the years ahead to observe the effects of the Thruway as it is extended to the New York City line and as the other sections are connected with the expressways of neighboring states.

One thing is clear, however. New and wisely-placed controlled access highways are urgently required elsewhere in New York State, as well as all across the Nation. They are absolute necessities, not only for traffic relief, but for the continued health and expansion of the economy.

The burning question is not whether we need controlled access highways, but how to finance them. Financing is outside my assignment today, but I would like to emphasize again this point: The tremendous toll that outmoded highways exact in lives, property damage, human misery and sheer economic waste alone compensate for the cost of providing a wholly adequate highway system. The average driver is paying as much as an extra cent a mile to travel on our outmoded free highway system. We are aware of these facts but we may fail to recognize the sweeping economic betterments which express highways create—the kind of betterments the Thruway has brought about even at this early stage.

We must balance the cost of constructing modern highways against many factors, but paramount among them is the economic growth and development that have become synonymous with new expressways and major highway construction programs. We have under-emphasized these benefits, in spite of the fact that they far outweigh the cost of providing the highways themselves.

Adequate highways are the very foundation of our national progress today. It's up to us as engineers to do our part technically and as citizens to help produce these modern economic foundations for our nation.

JOURNAL

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

CONTROL OF HIGHWAY ACCESS: ECONOMIC EFFECTS OF THE GULF FREEWAY

D. C. Greer,[1] M. ASCE
(Proc. Paper 872)

FOREWORD

The limitation or control of access to public highways is probably the major feature distinguishing modern highways from those built in earlier periods. True enough, the separation of grades at intersections, the dividing of highways to separate traffic moving in opposing directions and the provision for extra lanes to accommodate heavy traffic flows, are also embodied in the design of highways currently being constructed to provide for the ever-increasing numbers of moving motor vehicles. However, it is believed that the denial of abutters' rights to enter at will upon public highways is the fundamental change in the concept of a modern highway. This concept has been slow to evolve and a number of the American states do not yet have legal authority to construct highways which include access prohibitions. Other states have had such favorable acceptance of this principle, that they exercise access control whenever land is purchased for highway relocations. A few states go further and curtail roadside development by declaring certain existing highways to be freeways.

The purpose in arranging the Symposium was to broaden knowledge of the subject and to encourage greater use of this means of reducing the obsolescence of the highways needed for our motor vehicle economy.

SYNOPSIS

This paper presents a review of some of the conclusions drawn from investigations of the economic effects of limited access facilities upon adjacent properties together with a detailed account of the method of approach and conclusions of an economic survey of the Gulf Freeway in Houston, Texas, which was made in 1951. The increase in land values of adjacent properties after a period of five years is evaluated.

Note: Discussion open until May 1, 1956. Paper 872 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 82 No. HW 1, January, 1956.

1. State Highway Engineer, Austin, Tex.

The conditions governing the economic effect of limited access projects will vary. There appears to be no one set of values which might apply to all projects. It will be the purpose of this paper to present certain facts which have been established by several authorities and to cover the Texas experience reflected by the Economic Study of the Gulf Freeway of Houston in some detail.

Appraisers have been active in investigations of the effect of limited access facilities. Adrian F. McDonald of Hartford, Connecticut, reported in The Review, published by the Society of Residential Appraisers, in the issue of February, 1953, that "Observation and study over a period of several years appear to warrant certain general conclusions. Sections of Connecticut suitable for residential use and with easy access to the Merritt and Wilbur Cross Highway systems have increased in desirability, rate of marketability and value. Today it is easier to sell properties within a mile of the Connecticut Expressway routes than ever before, and at better prices." Speaking of towns in Fairfield County he states that "The results were so clear cut as to be remarkable in their consistency. Sales of land adjoining the Merritt Parkway and in the vicinity showed a substantially higher level of prices than comparable land some distance removed. Particularly noticeable was the high level of prices of those properties which were at a higher elevation than the highway surface. The only cases where lower prices were found were those involving adjacent land below the traveled portion of the road. Inquiry developed the fact that in these cases noise actually seemed to roll down to envelop these properties and the buying public recognized this phenomenon." In reference to the Wilbur Cross Highway he states, "In Greenwich and Darien in Fairfield County, sales for the past five years show absolutely no adverse effects from extremely heavy truck traffic on U.S. No. 1 even where the rear lines of properties may be within 100 feet to 150 feet of the traffic." In speaking of property adjoining, but without direct access to high speed express highways, he states that, "In cases where such properties are bordered by intersecting side roads or exit ramps from the expressway, there are innumerable instances in Connecticut of sales for business purposes at fabulous prices. This also is true of properties which are actually off the expressway proper but which are accessible to it by reason of access and exit ramps." He summarizes, "No general conclusion can be drawn except that there is no general rule applicable in all cases. The appraiser must analyze the problem case in the light of his own experience and market reaction. However, in Connecticut it seems certain generalities are true. Limited access expressways have drawn people as well as industrial plants from the city to the country. That has helped to curb (but not eliminate) increase in city residential values. On the other hand, both rate of marketability and values in outlying areas have tended to rise, many times in substantial degree."

Mr. Frank C. Balfour of the Division of Highways of California has reported many studies made of the California developments. In an article published in the Appraisal Journal in October 1954, certain statements seem pertinent to this discussion. "The Expressway, the Freeway, and the various types of toll roads are designed primarily to meet the needs of automotive transportation. The underlying principle of this type of highway design is to move the greatest volume of traffic with maximum safety and efficiency. The secondary consideration of the expressway is to serve the abutting property. However, we can demonstrate that the modern limited access highway facility's effect on both abutting properties and properties in the entire area of its influence

is so great, both from a monetary and psychological standpoint, that it far overshadows the immediately apparent benefits of the conventional highways." Mr. Balfour carries his discussion through industrial, commercial and residential development citing numerous examples of increase in land value by virtue of access to the freeway.

There are numerous authoritative reports on studies which might be mentioned here. The article of Mr. McDonald was used as it indicates some results influenced by construction features. The article of Mr. Balfour expressed in broad terms the findings which appear to be usual in all reported cases. A report on the study of the Gulf Freeway which represents Texas' experience follows in detail.

In May of 1950 the Texas Highway Department in cooperation with the Bureau of Public Roads initiated a study of the effect of the Gulf Freeway in Houston on adjacent land values and land use. Ensuing conferences between personnel of the Bureau of Public Roads, the City of Houston and the Texas Highway Department outlined a general method of procedure and agreed upon the objective of the study. These preliminary conferences brought out the fact that very much depended upon the data which could be obtained and that an extensive examination would have to be made before any definite procedure could be outlined. Negotiations with the Norris Engineering Company of Houston culminated in a contract based on a generalized outline of the proposed work in January of 1951. Mr. H. W. Elder of the firm was designated as Supervising Engineer of the project and such success as may be attributed to the study is due largely to his diligence and careful analysis of the problems that arose.

The portion of the Gulf Freeway in the City of Houston under study was 7.8 miles in length, extending from Main Street adjacent to and southwest of the central business district southeasterly to continue as a rural expressway to the City of Galveston. The first mile southeast of Main Street forms a four-street dispersal system with cross streets at grade. This section is provided with traffic light control for speeds of 30 m.p.h. The extension southeast within the city is of freeway classification.

Work on surveys and plans of the Gulf Freeway began in 1943 and dates the earliest realization of the facility. Construction on the first three miles from the center of the city southeastward began early in 1946 and the section was opened to traffic in October of 1948. In October 1951 approximately 6-1/2 miles were in operation. The remainder had not been placed in operation during the period of this study and, in fact, was not opened until August of 1952. The opening of the Freeway by increments had a natural effect on the transfer of ownership and development of properties reflecting in sales prices and shows to be translated in the findings of the study of land values. The greater increases in value appeared to follow after the facility was placed in use which may be partially due to speculation. A later survey, now projected, may modify this particular finding.

The change in land use is a matter of observation best shown by before and after photographs. There is evidence that the change is steadily proceeding adjacent to the Expressway as well as increasing in width of development. It will probably be a number of years before the activity becomes stabilized. It is reasoned that relative property values will increase as the property changes ownership and is placed to new, higher and better use brought about by the favorable position of the land in regard to the transportation facility. In this early interval, the principal development was on unimproved areas or areas with meager improvements.

The basic concept of the land value study was a comparison of land values reflected by actual sales prices of land areas along the Freeway with land areas at other locations in the city equally well served by the street system prior to the Freeway construction and equidistant from the civic center and of comparable environment and similar development and usage. The change in land value by virtue of its position was the quality chosen for measurement. The comparison would have been simple in application had all lands been vacant, or less complicated had all lands been occupied by similar improvements. Sales prices cover land with improvements. The land along the Freeway varied from large undeveloped areas through the stages of areas of very low type residential housing, decadent neighborhoods of once the best but now obsolete residential properties in the process of conversion to rooming houses and commercial properties, neighborhoods of modern, medium income residential housing, areas of modern apartment housing and areas of business properties, all varying within themselves. To arrive at land values as reflected by sales prices, a deduction of the sales price of improvements was therefore required. In the final analysis the price of land per square foot was used for comparisons, frontage conditions being disregarded because of complications.

Investigations revealed that assessments in Houston were based on 1940 appraisals at 70 per cent of the appraisal value. The assessments thus indicated the appraised value of the improvements on each parcel of land which was transferred and these values were accepted as the best information available. This premise brought into prominence the effect of the varying purchasing power of the dollar over a period of years and was responsible for the conversion of sales prices applied to improvements into three categories: (1) The dollar with no adjustment; (2) the dollar adjusted to the Consumers Index; and (3) the dollar adjusted to the Construction Index.

One of the major financial institutions of Houston made available their records of property sales in the city over a long period of years. These sales records, together with city assessment records, were the sources of data pertinent to the land value study.

In order that definite comparisons might be made, the length of the Gulf Freeway in Houston was divided into six sections dependent upon the nature of improvements and environment. These sections were further divided to delineate the portion immediately adjacent and parallel to the facility and designated as Group 1, and a secondary zone bordering and slightly more distant than the primary zone was designated as Group 2. Areas in all respects comparable to each of the sections of Group 1 but in various sections of the city where no influence of the Gulf Freeway might have been realized were selected for direct comparison of land sales prices and delineated as Group 4. Group 3, made up of a selection of areas at considerable distance from the Freeway but in the same quadrant of the city, was chosen and analyzed for the purpose of a check on comparative land values in the directional area of the Freeway.

All bona fide property sales in all sections for the years 1939 to 1941, 1945 to 1946, and 1949 to 1951 were examined. In the first period there were 858 sales; in the second period, 1041 sales, and in the third period, 397, totaling 2296 sales taken in consideration. In the 2296 sales there appeared 199 repeat sales. Repeat sales were separately analyzed because of interim improvements which entered the problem and the opportunity of enlarging the scope of the findings of the survey.

The route of the Freeway was well established in 1945 and construction started in 1946. For comparison of land values the period 1939 to 1941 was used as centering the 5 year interval before the Freeway became a reality. The 1949 to 1951 period was taken as representing the 5 year interval after the Freeway became a reality.

The most outstanding conclusions which are reached from an analysis of all sales are as follows:

1) During the five year interval after the Gulf Freeway became a potential factor of influence upon land values, properties adjacent or very close to the facility increased to a greater extent than in any other section of the city, and those in the secondary zone of influence increased in market value to a greater extent than did those farther removed from the facility; and

2) During this interval all methods of analysis used in the study bear the same directional trend indicating that the facility was a definite factor of influence on the increase in market values of properties in the areas through which the facility passes; and

3) During the five year period immediately preceding the period of potential influence of the facility, the increase in market value of properties adjacent to the future route of the Gulf Freeway was very close to the median of increases in all area groups studied.

The analysis of "repeat sales" of identical properties sold and resold after the freeway became a potential factor of influence in the community indicated that a property owner in the primary zone of influence had approximately twice as many opportunities to resell as did the owner in zones beyond the influence of the facility and that his gain on investment was substantially greater than that of the owner beyond the influence of the facility.

A comparison of the change in land values of the group of areas adjacent to the Freeway with the group of areas chosen to represent like properties in areas not influenced by the Freeway illustrates the similarity of the trend and close agreement in the extent of change in land value due to the Freeway regardless of the method used for deduction of the price of improvements from the sales price of the property. By expression of the relation of changes in land values between groups as the difference in percentages of value changes, the effect of a variation in the purchasing power of the dollar is minimized and a true comparison results. By this method, a valid conclusion may be drawn for the relation of land value changes for the five year interval between the time when the Freeway became of influence and the date of this survey. The percentage increase in land values along the Freeway over land values of the group of like properties not influenced by the Freeway is calculated as 81% where improvements were deducted without regard to a price index; 95% where improvements were deducted in proportion to the Consumers Price Index; 111% where improvements were deducted in proportion to the Construction Index; and 92% for repeat sales with improvements included. The reasonably close agreement in these percentages is convincing.

A report of this survey has been published under the title "A Study of Land Values and Land Use Along the Gulf Freeway." That volume has been widely distributed and appears to have been received with some interest by the highway fraternity. This is indeed gratifying to the Texas Highway Department.

As a practical application of the facts brought out in the report, the Texas Highway Planning Survey made an analysis of the study in regard to the justification of the right of way cost of this facility which cost was borne by the City of Houston. This analysis involved the assessed valuation of each section

of each group with relative percentage increases in total value of each section in the group along the Freeway as compared to similar sections not influenced by the Freeway. It was determined that if assessed and taxed proportionately, the increase in market value of lands along the Freeway over and above the increase in market value of the similar lands not so situated would yield revenue sufficient to defray the right of way cost in eighteen years. Allowing for the reasonable continuance of the trend, the increase should double within a few years. When this potential is accomplished, increased tax revenues of nine years would serve to defray the right of way expense to the city.

No two cities or conditions could be identical, but the fact that the construction of Freeways tends to increase the value of the adjacent land is believed to be established by this study, and the variance should be in degree only.

It is the intention of the Texas Highway Department to extend this study along the same lines for another five year interval in 1956. There has been considerable development in the areas along the Freeway which were studied in 1950. There should be a continuation of the land value trend in those areas. The most noticeable development, however, has been in the extension of residential areas beyond the original metropolitan area of Houston. It will be interesting to examine the effect on the original residential areas by reason of extending the acceptable travel distance to residential areas. A tendency toward leveling out of improvements in the zones adjacent to the Freeway will likely be indicated.

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CONTROL OF HIGHWAY ACCESS: EXPERIENCES IN INDIANA

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FOREWORD

The limitation or control of access to public highways is probably the major feature distinguishing modern highways from those built in earlier periods. True enough, the separation of grades at intersections, the dividing of highways to separate traffic moving in opposing directions and the provision for extra lanes to accommodate heavy traffic flows, are also embodied in the design of highways currently being constructed to provide for the ever-increasing numbers of moving motor vehicles. However, it is believed that the denial of abutters' rights to enter at will upon public highways is the fundamental change in the concept of a modern highway. This concept has been slow to evolve and a number of the American states do not yet have legal authority to construct highways which include access prohibitions. Other states have had such favorable acceptance of this principle, that they exercise access control whenever land is purchased for highway relocations. A few states go further and curtail roadside development by declaring certain existing highways to be freeways.

The purpose in arranging the Symposium was to broaden knowledge of the subject and to encourage greater use of this means of reducing the obsolescence of the highways needed for our motor vehicle economy.

SYNOPSIS

This paper covers the experience leading to the adoption and the use of Control of Access in Indiana. The evolution described involves the measures taken in an effort to handle traffic satisfactorily on the State Highway System, through the construction of By-Passes and Dual Lane pavements; the subsequent ribbon type development, which eventually led to the enactment of permissive Controlled Access legislation and finally, legislation which requires that all By-passes constructed must be Limited Access. High points of the legislative acts are quoted. The benefits of Controlled Access are enumerated as well as the conclusions.

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INTRODUCTION

Indiana's highway system had its inception in 1917; however, due to legal difficulties, the department did not get started on a permanent basis until November 1919. The greatest problem facing the department was that of getting the highways out of the mud at the earliest possible date.

In the succeeding years, this feat was accomplished, but to the dismay that the volumes and speed of traffic had conspired to make the major routes substantially obsolete. The Ideal Section 1.36 miles in length, constructed in 1922 and 1923 between Dyer and Schererville on U. S. 30, was a bold attempt to insert into the highway program higher standards. It consisted of a 40-foot pavement, wide shoulders, provision for walks, lighting facilities together with a number of landscape features, was widely advertised and conceived as a pattern for all highways in the future. As far as the Indiana program is concerned, it never achieved the glory of its name.

The year 1935 witnessed the advent of another revolutionary facility, that of the divided lane highway at grade, except for separations at railroads. As first conceived, a minimum right-of-way of 200 feet was established with two 22-foot pavements separated by a 44-foot median strip. The first section, opened in 1937, was on U. S. 30 from U. S. 41 to Cline Avenue,—a distance of 2.23 miles. Since that date, a total of 308 miles of dual lane highways throughout the State have been completed.

By-passes have also played an important part in the Indiana Highway System. At one period, they were hailed as the answer to the alleviation of traffic congestion in urban areas. From 1922 to 1954, 40 by-passes were constructed in Indiana, all as grade facilities. Because access was not controlled, a ribbon development of residential and business structures sprung up along the by-passes serving the larger urban areas, to a point that they have actually become little more than congested city streets. As an example, the by-pass at Lafayette, built in 1937 and presently carrying volumes in excess of 11,000, has been so solidly hemmed in in the intervening years by commercial and residential developments, that as a part of the interstate system, it will require relocation approximately one-half mile farther out.

The control of access had its earliest consideration in 1944, at which time the first origin and destination traffic survey was conducted in the City of Fort Wayne. The recommendations of this survey, presented in a 1946 report, called for an expressway system as a long range solution of its traffic problem.

This system was to be developed over a 10-year period at an estimated cost of $26,000,000. The Highway Department and the City of Fort Wayne entered into an agreement to proceed with its construction; providing, it was acted upon favorably in a referendum vote to be held in the fall of 1947. In spite of a concerted publicity effort by the City, the citizens in sufficient number voted against the project.

This action had a demoralizing affect on the Highway Department to the extent that consideration of the use of expressways within urban areas was ruled out of the picture for other studies pending at that time.

However, in 1948, first contracts were awarded on the Tri-State Highway in Lake County from the Illinois line east approximately 2 miles. This facility, designed as limited access, was Indiana's continuation of the Illinois section of the Tri-State Highway, which also was put under construction during the same period. The first section was completed and opened to traffic

in 1951. Since that date, an additional .7 of a mile has been opened and 3.9 miles now under construction will be completed in 1956.

Other examples of full or partial limited access facilities now under construction, or soon to be put under contract, include:

US 31-E	in Jeffersonville	- Approx. 2.2 miles	(Ohio River to Kopp Lane)
US 31	in Indianapolis	- Approx. 2.3 miles	(Madison Ave.)
SR 100	in Indianapolis	- Approx. 3.0 miles	(US 40 to US 421)
SR 37	Indianapolis to Noblesville	- Approx. 19.0 miles	
SR 62	at Evansville	- Approx. 8.5 miles	(2nd Ave. west to County line)
US 30	in Fort Wayne	- Approx. 1.2 miles	(Beuter Road E. to Int. US 30)
US 52	Templeton By-pass	- Approx. 2.0 miles	
US 41	Morocco By-pass	- Approx. 4.0 miles	
US 41	Schneider By-pass	- Approx. 5.2 miles	
	Total	47.4 miles	

These facilities, when opened to traffic, will give the public an opportunity to recognize by actual use their advantages and will encourage the development of similar projects.

This record of limited access facilities, constructed to date in Indiana, reveals the surface has been barely scratched. The essential need to resort to a more extensive use of limited access standards has been uppermost in the minds and plans of the department; only the lack of adequate finances and a long range policy have prevented their adoption. However, conditions have changed since August of 1954 and the picture now appears brighter.

Highway Performance

In the introductory remarks we have covered briefly the picture in Indiana, showing that the State Highway System was developed with but few exceptions, with no control of access. That is, unless some extenuating hazardous condition existed, a property owner could gain permission to build a driveway onto any highway; therefore, the greater the volume of traffic and the nearer to an urban area, the greater the number of driveways. On every important route entering the urban centers, we now find this ribbon type of development which, as far as traffic movements are concerned, acts to reduce the route to the qualities of a congested city street.

The expectation that by-passes, because of their construction on new locations free from built up conditions, would provide a large measure of relief to traffic has not proved entirely satisfactory in the larger urban areas. It has been demonstrated conclusively that, because accesses were not controlled, residential and commercial developers have immediately taken advantage of the ideal location opportunities of these facilities, to proceed unrestricted with their construction.

Examples of how extensive this build up has been on a number of by-passes will serve to show the seriousness of continuing on an unlimited policy. On a 4.2 mile section of the Marion By-pass, built in 1940-1942, there exists 138 access points—one every 150 feet. On the Kokomo By-pass, built in 1948-1950, there are 159 access points in the 7-mile length—one every 235 feet. For the Lebanon By-pass, built in 1951, there are 57 access points in the 5-mile length—one every 465 feet. For the Fort Wayne By-Pass, built in 1948, there are 110 access points in a 3-mile length—one every 143 feet.

By-passes located at the smaller urban centers, where extensive build up has not taken place, have and are serving traffic in an effective way.

Mr. Wayne Kellams, Assistant Publicity Director of the Indiana Toll Road Commission, in a recent newspaper article, stated that a driver using the Indiana 156-mile east-west toll road (now under construction), instead of U.S. 20 would avoid:

74 Stoplights
17 Railroad Crossings
1 Drawbridge
15 School Zones
88 Heavy traffic entrances and exits
20 Major highway crossings
603 Minor traffic entrances and exits

The other major trunk highways in the State would show similar statistics and in some cases, even more access points, all pointing to the absolute need to give serious consideration to the control of access.

The 308 miles of dual lane highways in the State have proven a very effective facility in the handling of traffic. 221 miles of this mileage are located on the Interstate System which, preliminary studies indicate, can be brought up to limited access standards. Built up conditions on this mileage are substantially limited to the intersections, which will offer the most difficult problems in the program of the separation of grades and the construction of interchanges.

Controlled Access Facilities - Interstate Highway System

Without question, the issuance on August 4, 1954 of the far-reaching memorandum 20-4 by the Bureau of Public Roads to the States, defining the standards applicable to the Interstate Highway System, has set the pattern for the nation to follow. The memorandum states that federal interstate funds can be approved only on the basis that such routes be designed and constructed to free way standards.

The immediate impact of this federal pronouncement was met with the usual skepticism, that while a very lauditory move, where will the money come from to meet the high costs of such a program? However, the excellent possibility that the President's program, even though defeated in the 1955 session of Congress, will be seriously considered in 1956 and either the President's plan or a compromise thereto will be passed, has created high optimism that the program will become an eventuality.

Since the advent of this memorandum, the State Highway Department of Indiana has taken steps to conform to the new federal policy. The Indiana Interstate System consists of approximately 1,100 miles on 9 different routes. In accordance with a directive from the Highway Commission, a comprehensive study of the system is now proceeding intensively, so that if and when the federal program is approved and the go sign given, Indiana can proceed without delay.

The study involves the evaluation of the present interstate highways in order to determine whether they can be brought up to limited access standards on the existing alignment or will require complete relocation. In eliminating all direct access to the new facilities, the problem of providing adequate service roads will be paramount, particularly where the existing alignment is to be followed.

Our first study considered the section of U.S. 52 between Indianapolis and Lebanon, approximately 20 miles in length, which is at present principally a 3-lane pavement with some sections improved to four lanes. The right-of-way is approximately 100 feet in width with considerable ribbon development. Comparative studies revealed the advantage of a complete relocation of a minimum of 700 feet to a maximum of one-half mile distance away from the existing route. The old route can continue to serve local traffic with a resulting minimum need for service roads. Field surveys are now under way on the relocation line for the development of this route to full interstate standards.

The study of the Indiana Interstate Highway System will require approximately two years to complete. An aerial survey was made of the entire system in the spring of 1955 with the widths of coverage ranging from 1 to 4 miles. On several of the routes, it already appears from preliminary investigations, that reflying will be necessary because of the advantage of relocating greater distances from the existing alignment than was originally anticipated. These aerial views not only provide the basis of the detailed studies, but the final recommended alignment and major design elements thereof, will be depicted on strip maps developed from mosaics of the aerial contact prints.

The purpose of the study is to have the planning of the interstate system sufficiently advanced by the time funds become available so that the State can proceed on the program at full speed. The failure of the proposed program to be approved in the 1955 session of Congress will insure additional time for the planning and getting ready of a considerable number of projects for immediate construction.

Control of Highway Access in Indiana - By-Passes

The Highway Commission adopted a policy of building by-passes to limited access standards during the early part of 1954. Previous commissions had been urged to take this step, because of the growing number of cases where the constructed by-passes were definitely headed for obsoleteness. Four by-passes under construction at the time of the adoption of the new policy were, previous to their opening or during construction, declared limited access facilities, excepting only access points included in the contract plans. The State has 9 by-passes which are now in various stages of planning and which will be built to limited access standards.

Limited Access - Legislation

Definition

The first limited access legislation in the State of Indiana was enacted March 7, 1945. Following are important excerpts of the law: "A 'limited access facility' is defined as a highway or street especially designed for through traffic, and over, from, and to which owners or occupants of abutting land or other persons have no right or easement or only a limited right or easement of direct access, light, air, or view by reason of the fact that their property abuts upon such limited access facility or for any other reason. Such highways or streets may be parkways, from which trucks, busses, and other commercial vehicles shall be excluded; or they may be free ways open to use by all customary forms of street and highway traffic."

Cooperation - Local Agencies

"The highway authorities of the state, counties, cities, and towns, acting alone or in cooperation with each other or with any federal, state, or local agency of any other state having authority to participate in the construction and maintenance of highways, are hereby authorized to plan, designate, establish, regulate, vacate, alter, improve, maintain, and provide limited access facilities for public use whenever such authority or authorities are of the opinion that traffic conditions, present or future, will justify such special facilities—Provided, That within cities and towns such authority shall be subject to such municipal consent as may be provided by law." "Said units may regulate, restrict, or prohibit the use of such limited access facilities by the various classes of vehicles or traffic in a manner consistent with this act."

Traffic Regulation

"The State Highway Commission of Indiana and the proper authorities of any county, city, or town having charge of any highway or street affected by this act, are authorized to design any limited access facility and to regulate, restrict or prohibit access as to best serve the traffic for which such facility is intended. In this connection such authorities are authorized to divide and separate any limited access facility into separate roadways by the construction of raised curbings, central dividing sections, or other physical separations, or by designating such separate roadways by signs, markers, stripes, and the proper lane for such traffic by appropriate signs, markers, stripes and other devices. No person shall have any right of ingress or egress to, from, or across limited access facilities to or from abutting lands, except at such designated points at which access may be permitted, upon such terms and conditions as may be specified from time to time by rules and regulations adopted and promulgated as by law provided."

Property Acquisition

"For the purposes of this act, such authorities of the State, counties, cities, or towns, may acquire private or public property and property rights for limited access facilities and service roads, including rights of access, air, view, and light, by gift, devise, purchase or condemnation in the same manner as is now or hereafter may be provided by law to acquire such property or property rights for the laying out, widening or improvement of highways and streets within their respective jurisdictions." "The rights of all property owners who may claim damages, as provided by the Constitution of the State of Indiana, are preserved herein and may be enforced under the present laws of the State of Indiana."

"Court proceedings necessary to acquire property or property rights for purposes of this act shall take precedence over all other causes not involving the public interest in all courts, to the end that the provisions of limited access facilities may be expedited."

Powers of State and Local Authorities

"The highway authorities of the state, county, city, or town, may designate and establish limited access highways as new and additional facilities or may designate and establish an existing street or highway as included within a limited access facility. The state or any of its subdivisions or municipalities

shall have authority to provide for the elimination of intersections at grade of limited access facilities with existing state and county roads, and city and town streets, by grade separation or service road, or by closing off such roads and streets at the right-of-way boundary line of such limited access facility; and after the establishment of any limited access facility, no highway or street which is not part of said facility shall intersect the same at grade. No city or town street, county or state highway, or other public way shall be opened into or connected with any such limited access facility without the consent and previous approval of the proper authorities of the state, county, city, or town having jurisdiction over such limited access facility. Such consent and approval shall be given only if the public interest shall be served thereby."

Financing

"The State Highway Commission of Indiana may enter into agreements with the respective counties, cities and towns of the state or with the federal government, and such cities and towns may enter into agreements with the federal government, respecting the financing, planning, establishing, improvement, maintenance, use, regulation, or vacation of limited access facilities or other public ways in their respective jurisdictions, under this act or under any state and/or federal laws authorizing such cooperation, to carry out and facilitate the purposes of this act."

Location and Vacation of Roads and Streets

"In the carrying out of the purposes of this act and in the development of any limited access facility the State Highway Commission of Indiana and the several counties, cities and towns of the state are authorized to plan, designate, establish, use, regulate, alter, improve, maintain, and vacate local service roads and streets or to designate as local service roads and streets any existing road or street, and to exercise jurisdiction over service roads in the same manner as is authorized over limited access facilities under the terms of this act, if in their opinion, such local service roads and streets are necessary or desirable."

Traffic Regulation Penalties

"It is unlawful for any person (1) to drive a vehicle over, upon, or across any curb, central dividing section, or other separation or dividing line on limited access facilities; (2) to make a left turn, a semi-circular, or U-turn except through an opening provided for that purpose in the dividing curb section, separation, or line; (3) to drive any vehicle except in the proper lane provided for that purpose and in the proper direction and to the right of the central dividing curb, separation section, or line; (4) to drive any vehicle into the limited access facility from a local service road except through an opening provided for that purpose in the dividing curb or dividing section or dividing line which separates such service road from the limited access facility proper. Any person who violates any of the provisions of this section is guilty of a misdemeanor and upon arrest and conviction therefor shall be punished by a fine of not less than one dollar ($1.00) nor more than fifty dollars ($50.00) or by imprisonment in the city or county jail for not less than five days nor more than ninety days, or by both such fine and imprisonment."

Amendment - Limited Access By-Passes

On March 8, 1955 an amendment to the 1945 law was passed specifically directing the Highway Commission to designate and construct all by-passes to limited access standards. The law states —"Whenever the State Highway Commission constructs a by-pass highway around any city or town, the Commission shall be required to designate and establish such by-pass highways as limited access highways."

From the foregoing it can be seen that broad powers have been granted for the establishing of limited access facilities.

Limited Access - Resolutions

In order to protect the dual lane sections now in service on the interstate system, resolutions declaring the respective sections to be limited access highways, excepting those access points existent at the time of the field inventory, have been prepared and approved by the Commission. Limited access signs 36 inches square in size have been placed on all routes covered by resolutions, alternating left and right at 2-mile intervals at the right-of-way line and facing the highway. The sign carries the following message—"Limited Access Facility, Direct Access Will Not Be Granted—Before Planning Improvement on Adjoining Property—Contact Indiana State Highway Dept. —102 North Senate Ave., Indianapolis, Ind."

Previous to the erection of the signs along the routes, newspaper and radio publicity was provided. In most cases, the newspapers carried the message as front page material. Directives were sent to the 6 District Offices instructing them to deny all permits on the resolution covered sections of highways. In those cases where the applicant insisted the driveway was essential, and where no other access outlets were available, he was referred to the Central Office.

Fortunately, to date, these resolutions have proven very effective as a major deterrent to further granting of access permits. The cooperation of property owners and commercial interests has been unusually fine, in that following a thorough understanding of the purpose of these resolutions, they have signified their intention of either abandoning their application request or have accepted an alternate solution offered by the Commission.

Control of Access - Benefits

The benefits of limited access highways may be broken down into two classifications—First, those which directly accrue to the highway user and—Second, those which the State and its citizens derive in the form of reduced highway residential and business construction costs and losses due to the permanence of limited access highways.

The direct benefits to the highway user include:

1) The uniform speed which can be maintained over a limited access route results in time savings to the motorist, dependent on the length of the trip. The translation of this time saved to a monetary basis results in large savings, particularly to commercial interests.
2) Fuel consumption is reduced by the elimination of stops, slow down regulations, etc. Due to a uniform travel speed, void of stops, etc., maintenance costs on the vehicle in the form of tire wear, and mechanical repairs are reduced.

3) A most important benefit lies in the reduction of accidents which statistics show, will be approximately 10% to 50% of those on an uncontrolled access highway. For example, in California, the death rate per 100 million vehicle miles was 2.12 on all free ways, and 9.39 on all rural highways. In Maine, 2.8 on the Maine Turnpike, on parallel U.S. 1, 22.3; in Michigan 6.7 on the Detroit Industrial Expressway, on parallel U.S. 112, 15.0. (Reference "The Highway Magazine," Sept. 1955).

The indirect benefits which are not so immediately tangible but are real and very important have to do with eliminating the very costly item of highway obsoleteness. The limited access highway has all the attributes necessary to fix it as a permanent improvement. The alignment is fixed permanently because of the control of all access and its service to traffic continues unabated. As the volumes of traffic increase, sufficient right-of-way is available to add the needed additional lanes. Residential and commercial construction are thus provided with a fixed location, to which they can plan an orderly development without the future possibilities of losing their investment because of a relocation.

CONCLUSIONS

The adoption of the controlled access type of highway by the Indiana State Highway Department for the Interstate System, the major state routes and all by-passes is the most significant step ever taken in its history. Widespread publicity has been given the new policy, with most encouraging response from all parts of the state acclaiming the wisdom and advantages of the new type of highway.

Property owners and business interests, both by letter and personal conferences to and with the State, have been and are trying to set up their programs of development in order that they will fit into the future facilities. As far as possible, the State is cooperating with these individuals so that the change to the new standards will cause a minimum of disruptment.

The concern in the program now is the element of time and until the President's plan or a compromise thereof is approved by Congress, there can be little active construction progress on the Interstate Highway Program in Indiana. The tone of the thinking is most optimistic, that a definite plan will be enacted by Congress in 1956, which will make it possible for the State to set its program in action. Additional legislation will be required by the State to provide adequate matching funds for such new grants. There is every reason to believe that the vehicle owners will respond to higher taxes if they are definitely assured it will provide limited access facilities.

The picture, therefore, appears most heartening in Indiana, that we are on the very threshold of a new era in highway building that will not stop with merely reconstructing the interstate system, but which will carry over to include a great many of the major traffic arteries in the State.

JOURNAL

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

CONTROL OF HIGHWAY ACCESS: EXPERIENCES IN LOS ANGELES

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(Proc. Paper 874)

FOREWORD

The limitation or control of access to public highways is probably the major feature distinguishing modern highways from those built in earlier periods. True enough, the separation of grades at intersections, the dividing of highways to separate traffic moving in opposing directions and the provision for extra lanes to accommodate heavy traffic flows, are also embodied in the design of highways currently being constructed to provide for the ever-increasing numbers of moving motor vehicles. However, it is believed that the denial of abutters' rights to enter at will upon public highways is the fundamental change in the concept of a modern highway. This concept has been slow to evolve and a number of the American states do not yet have legal authority to construct highways which include access prohibitions. Other states have had such favorable acceptance of this principle, that they exercise access control whenever land is purchased for highway relocations. A few states go further and curtail roadside development by declaring certain existing highways to be freeways.

The purpose in arranging the Symposium was to broaden knowledge of the subject and to encourage greater use of this means of reducing the obsolescence of the highways needed for our motor vehicle economy.

SYNOPSIS

This paper discusses briefly the history of the Freeway System in the Los Angeles Metropolitan Area, the accomplishments to date in construction of the units of that System, the direct and indirect benefits already derived from the completed units and the benefit to be obtained from a completed integrated system of freeways.

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INTRODUCTION

The City of Los Angeles has long been an advocate of controlled access highways or freeways. Having an area of 453 square miles, in the hub of a metropolitan area of over 1200 square miles, it has through the years become increasingly dependent on automotive transportation. The large volumes of traffic and the relatively long distances of travel have demanded highways with high capacity and designed for high overall speeds with safety. Modern urban freeways built to present day standards will in our opinion best provide for this area the rapid transit elements of an effective urban transit system.

Beginning in 1937 and constructing as rapidly as projects could be "sold" and rights of way acquired, within the limitations of available funds and war time restrictions, there are now 72 miles of freeways in operation and 34 miles currently under construction. Routes have been adopted for 180 additional miles on which right of way is being protected or acquired and for which plans are being prepared.

To date the freeway program represents the expenditure of about $300,000,000. In excess of $65,000,000 per year is now being expended on approved freeway projects. There are 620 miles of freeways, inclusive of those already listed, in the approved Master Plan of Freeways.

A complete discussion of the present state of development of the freeway system in the Los Angeles area is available in the article entitled "District VII Freeways" included in the January-February 1955 issue of "CALIFORNIA HIGHWAYS AND PUBLIC WORKS" and written by P. O. Harding, Assistant State Highway Engineer.

Figure 1 accompanying this paper shows the freeway units completed or under construction, budgeted and under freeway resolution (routes adopted).

Figure 2 shows the Proposed Freeway System for the Los Angeles Metropolitan Area as it is generally approved by the political jurisdictions affected.

From analysis of the units completed and by projecting their demonstrated benefits to projects proposed for construction, it is possible to show that the Los Angeles Area has received and will continue to receive tremendous dividends from its freeways.

Early History of the Freeway System

Growing street traffic congestion and mass transit inadequacies finally resulted in major action by the City of Los Angeles in 1937 to correct these conditions. As a first step the Mayor, backed by a Citizens' Transportation Committee, appointed a Transportation Engineering Board and charged it with the task of studying the problem and coming up with some definite recommendations. The Board was composed of Mr. Lloyd Aldrich, City Engineer, as Chairman, K. Chas. Bean, Chief Engineer, Dept. of Public Utilities and Transportation, and Stone & Webster Engineering Corporation, represented by Mr. Rudolph Weber, as members. The services of Stone & Webster Engineering Corporation and Madigan-Hyland were furnished by the Citizens' Committee.

There followed an extensive traffic and transportation survey, participated in by the Federal Work Projects Administration, and the analysis thereof, extending over an 18 month period. Result was two reports, the factual report "Report of Traffic and Transportation Survey" and in December 1939 "A Transit Program for the Los Angeles Metropolitan Area" which outlined the general findings and recommendations of the Board.

The program of the Board was essentially as follows:

1) The adoption of a comprehensive freeway plan designed to serve the needs of the entire metropolitan area;

2) The progressive construction as rapidly as financing can be provided of the units of the freeway plan;

3) The use of the freeways by express buses and the provision of bus loading facilities adjacent to the freeway roadways;

4) The provision of wide medians, where indicated, in the freeways for future rail rapid transit use;

5) Coordination of surface transit operations with the express bus and rapid transit routes along the freeways;

6) The eventual construction of standard type rail rapid transit facilities in the central business district and elsewhere to supplement the routes along the freeways, as growth of the Area warrants this.

The program was proposed recognizing the predominant use of the private automobile as a transportation medium, but with as much emphasis as possible on providing a rapid transit bus and rail service which would encourage greater use of mass transit.

The Report was received with general enthusiasm by officials and the public, though accomplishment of its recommendations would obviously involve years of effort and tremendous expenditures.

The freeway program proved to be the most practical of accomplishment and units thereof were early under way. The general success of the freeway program has been due to the marvelous cooperation of many persons and organizations. Officials have been very responsive. City, county and state engineers and planners have collaborated to the fullest extent in the location and engineering of the routes. Civic organizations such as the Metropolitan Traffic Association, Los Angeles Chamber of Commerce, Automobile Club of Southern California, Downtown Business Men's Association, and many others, have been towers of strength, individually and collectively, in defending the freeway principle, in obtaining necessary legislation, increased financing, legislative body approvals, and in helping to offset vigorous opposition to specific freeway routes.

While the proposal and advancement of the freeway program in this area is certainly the work and effort of many people, no one played a greater part in its conception and accomplishment than Lloyd Aldrich, Chairman of the Transportation Engineering Board and City Engineer, from the beginning of the freeway idea to its present state of general approval and its tremendous construction program. It was his vision that foresaw the need for these vital facilities. His energy and devotion to the freeway cause were many times the dynamic force that kept this program going at its ever increasing pace. Mr. Aldrich retired as City Engineer on August 31, 1955, but will continue to be a strong force for freeway construction as a citizen devoted to the provision of the public works necessary to keep pace with this most rapidly growing area.

The Freeway System on Its Way

Although the freeway plan as a whole received its first official approval in 1941 by the City Planning Commission, units of the system were underway before that time. The State Highway Division was already acquiring rights of way for sections of the San Bernardino and Santa Ana Freeways outside Los Angeles City.

A five mile section of the Pasadena Freeway, constructed mostly in a natural canyon through lands which had been acquired for park purposes, was completed and put into operation in 1939 shortly after presentation of the Report. This freeway replaced an existing State Highway Route, Figueroa Street, which passed through the business and commercial area of the Highland Park District of the City of Los Angeles. Its construction was vigorously opposed by the business men of that thoroughfare, who felt that removal of the through traffic would seriously affect their business. These same merchants are now enthusiastic in their approval of this freeway. Removal of the heavy traffic from Figueroa Street has greatly improved accessibility to their establishments by both vehicular and pedestrian traffic. In addition it has resulted in a general growth and betterment of the entire adjoining district.

Simultaneously a 1.3 mile section of the Hollywood Freeway through Cahuenga Pass, a natural traffic bottleneck and major connecting route between Los Angeles proper and its San Fernando Valley Section, was opened to traffic. Greater ease of travel increased the daily traffic volume through this Pass from 40,000 to 60,000 cars shortly after the freeway was opened. It has since gone up to over 160,000 cars per day.

The first fully urban freeway passing through a highly developed area of the City to be put in line for construction was the combination of the Hollywood Freeway from Vermont Avenue to the Civic Center and the Santa Ana Freeway from the Civic Center to the East City Boundary at Indiana Street. These freeways with their subsequent extensions were adopted as the permanent routing for State Route 2 (U. S. 101), an exceedingly important route traversing the City from Northwest to Southeast. No particular opposition was encountered in adopting the first section, but the section through the Hollywood District of the City of Los Angeles was bitterly opposed. This opposition delayed approval of the freeway agreement between City and State for over a year, during which time and even thereafter numerous hearings were held before City Council, State Highway Commission, and even State Legislature Interim Committees.

It has been characteristic of almost every freeway unit that their proposed location and construction has been vigorously protested. This has been the case even though the preponderance of public sentiment is favorable to freeway construction. It was believed that as more freeways were put into operation and their benefits were realized that such opposition would decrease. This has not been so. Here then the cooperative and independent studies by City and State engineers of available routes with their advantages and disadvantages have proved invaluable in obtaining final decisions. It has also been generally characteristic that once the routing has been approved most of the opposition dies down and there is a general demand for quick action to get the freeway into operation.

From these early freeway accomplishments there has followed successively and at constantly increasing rate the adoption of routes, acquisition and construction of freeways included in the Master Plan. These freeways have all been constructed as units of the State Highway System with gas tax and motor vehicle funds, including Federal Aid Funds made available for this purpose. Gas tax was increased 1-1/2 cent in 1947 and another 1-1/2 cent in 1953, resulting in a present rate of freeway acquisition and construction of about $60,000,000 per year.

Probably the most helpful measure ever passed to assure the eventual construction of the freeway system at right of way prices within the realms of

the possible was the passage of the Act to permit advance purchases of vacant properties along adopted freeway routes. This Act sets up a 30 million dollar revolving fund, reimbursable from the regular highway funds when allocated for right of way acquisition along a freeway project. It is estimated that to date the local State Highway District has, by the expenditure of $20,300,000 of these funds, effected a savings of $133,655,000 in ultimate right of way costs in this rapidly growing area where huge tracts of residences or new commercial areas or industries may spring up almost overnight. Here is a real dividend, collectible because we have an approved freeway system. This Act has greatly encouraged the official establishment of routes well in advance of construction and thereafter the protection of right of way by use of this revolving fund.

Another advantage of advance establishment of routes is the assurance and stability it gives to the districts traversed. Properties can then be developed with confidence and knowledge of what will happen when the freeway is constructed. It is the uncertainty of not knowing just where the freeway is going that creates unrest, hampers development, and actually lowers property values. Route adoption therefore is an intangible asset of considerable value.

All financing of the freeways so far has been on a pay-as-you-go basis. This method insures that highway funds are directly used in acquisition and construction and that there is no loss in interest charges. However, it does automatically limit the rate of construction to the amount of funds in hand. These have been insufficient. It is believed by many that the provable benefits of the freeways are so great that they would more than offset the interest payments were the remaining badly needed freeways to be constructed at a much more rapid rate by bond financing.

The remainder of this paper will deal with the demonstrated benefits which we have already enjoyed from our freeways in actual operation.

Demonstrated Benefits of the Freeways

Safety

In spite of general official approval of the freeway plan and acceptance of the freeway idea by the public, there began to be a growing criticism by the press and public of the alleged "high accident" rate and the "high speeds" of the traffic using the freeways. Serious recommendations were made for limiting the speeds on the Pasadena Freeway to 45 miles per hour to reduce the supposed high accident rate.

While our Bureau is primarily a design organization, it appeared the part of wisdom, in defense of the freeway principle, to assemble the facts and to place these records before the public to offset some of the growing opposition and unfounded criticism. This office therefore undertook a study resulting in our first Report entitled "Comparison of Parkways (Freeways) with Surface Streets in Capacity, Time Saving, and Safety" published in November 1951 and given widespread publicity.

In this study, for purpose of comparing with existing freeways, we selected the following surface streets:

1) Wilshire Boulevard, a major east-west traffic artery from downtown Los Angeles to Beverly Hills, length 6.98 miles.

2) Figueroa Street, a north-south State Highway from downtown Los Angeles to Imperial Highway, length 8.29 miles.

These are well controlled boulevards carrying heavy traffic loads under conditions normal to city streets. In a 3 year period chosen for comparison purposes (1948-1950 inclusive) travel on these arteries totaled 600,000,000 vehicle miles.

To compare with these arteries the following freeways were in operation over the same 3 year period:

1) Pasadena Freeway, Glen Arm Street, Pasadena, to College Street, 6.12 miles.

2) San Bernardino Freeway, Vignes Street to Indiana Street, 2.3 miles.

3) Santa Ana Freeway, Vignes Street to Ditman Street, 3.8 miles.

4) Hollywood Freeway, Odin Street to Vineland Avenue, 3.07 miles.

Travel on the Pasadena Freeway totaled 426,000,000 vehicle miles and all of the above freeways accounted for 776,100,000 vehicle miles. Comparisons are therefore proportional as to volumes of traffic.

Of the above freeways, the Pasadena Freeway had been in operation for about 10 years. Being the first of the local freeways constructed, it is not up to the standards of our more recent ones. The roadways do not have the continuous shoulders now provided, but only occasional parking bays recently added. The freeway has narrow median strips, curve radii as low as 515 feet, inadequate or no accelerating and decelerating lanes at ramp connections, and insufficient side clearances to piers and abutments. The San Bernardino Freeway, following an existing surface boulevard, is likewise of lower design standards. The 3 last named freeways are all quite short. The abrupt transition from freeway conditions to surface street conditions at the several temporary terminii creates a relatively high accident potential and in fact most of the recorded accidents occurred at these points.

No records were then available for the newly opened sections of the Hollywood Freeway, which is in fact the first of our local freeways to be constructed to modern design standards. In view of these facts the demonstrated safety advantages of the above listed freeways over the surface arteries are all the more remarkable.

Tabulating recorded accidents on the surface arteries and freeways indicated the following:

	Rates per 100 million Vehicle Miles for 1948-50 (3 years)	
Facility	Fatality Accident	Combined Fatality & Injury Accident
Pasadena Freeway	0.7	46.5
Hollywood, San Bernardino and Santa Ana Freeways	2.9	60.0
Combined Freeways	1.7	53.9
Combined Figueroa St. and Wilshire Blvd.	4.2	259.8

Examination of this table indicates the combined accident rate of the surface arteries for the 3 year period to be 5.6 times that of the Pasadena Freeway and 4.8 times that of the combined freeways. The fatality rate of the surface arteries is 6 times that of the Pasadena Freeway and 2-1/2 times that of the combined freeways.

A summary of fatal freeway accidents through 1954 indicates the Hollywood Freeway fatalities per 100 million vehicle miles as 1.44 based on 1179 million vehicle miles of travel, showing the to be expected more favorable effect of modern design on the fatality rate. The combined experience to date on the freeways through 1954 has been 2.25 fatalities per 100 million vehicle miles. This compares to 5 per 100 million vehicle miles for surface streets.

The injury accident rate in 1954 for all surface streets is 175 per 100 million vehicle miles as compared to 57 per 100 million vehicle miles for freeways.

Published statistics for the New York Thruway System now in operation indicate 5 deaths in over 205 million vehicle miles, or a fatality rate of 2.44 per 100 million vehicle miles. This compares to a rate of 6.1 per 100 million vehicle miles for New York State highways during 1953.

The above figures indicate a most favorable record for the freeways which fully justifies the assertion that there is a very decided advantage from a safety standpoint in freeway travel over that of a highly regulated, heavily used urban surface artery.

Although figures show freeway travel to have decided advantages, we as engineers, highway builders and administrators cannot afford to be complacent about our accomplishments. Accidents do occur on freeways and we should know more about them. We are actively studying this matter.

By plotting the accidents as to location, type and severity, we can determine whether there are accident prone locations. Sometimes the contributing condition is then easily seen. At other times the cause is not so easily seen. As engineers we are particularly anxious to know whether geometric design features have been contributory to the more severe freeway accidents.

A brief summary of the 46 accidents resulting in 56 deaths on our freeways to date is of interest. Eleven of the drivers involved in the 46 accidents were listed by the police as being drunk. Two more were known to have been drinking. In only 2 of the 11 accidents involving drunk drivers was anyone other than the driver or an occupant of his car killed. Five deaths were pedestrians, of which one had been drinking and one was a flagman struck at only 15 miles per hour. Only one accident was attributable to mechanical failure resulting in the car crossing the center strip.

Drivers 25 years or under accounted for 20 of the 46 accidents. In 29 of the accidents only one vehicle was involved. Sixty-nine percent of the accidents occurred during darkness, though only thirty percent of traffic is at night.

Inadequate freeway design standards appeared to be a minor contributing cause. Where it was the cause, the design was usually inferior to present standards. Four of the five accidents on the San Bernardino Freeway appear to be in this category. In three of these cases the narrow divider strip was crossed on curves less than present minimum standards. The fourth occurred where on-coming traffic is introduced into the high speed lane. Nine accidents occurred at off ramps (two involving drunk drivers). Two of these cases may be attributable to inferior design.

The above summary of fatal accident causes show clearly that a freeway

constructed in accordance with the present high standards of design is inherently a facility of outstanding traffic safety when rightly used. It can well be expected that with better operating and regulating techniques as they are being studied and developed by the traffic engineers and enforcement officers, the safety record can be measurably improved in the days ahead.

Capacity

Our next comparison was the relative capacity of the freeway as compared to the urban surface traffic artery. To secure the maximum use of the traveled surface streets in our urban area, 4 to 8 traffic signals per mile are necessary. All of the methods known to traffic engineers are also resorted to, including parking bans, prohibiting left turns, and off center laning. All of these, while necessary for maximum capacity and safety, penalize the individual driver at some point in his journey, as well as the lesser streams of traffic crossing the major arteries. The result of all of this is that the most favored surface arteries carry a maximum of about 625 vehicles per lane per hour. This compares to many freeway lanes where measured traffic is 1800 vehicles per lane per hour or more, and where lanes operating under some pressure are carrying as many as 2200 vehicles per lane per hour over sustained periods.

Time Savings

Charges of high speeds on the freeways were also not sustained by facts. More than 10,000 radar readings on the Pasadena Freeway have established an average speed of 46.4 miles per hour between 7:00 A.M. and 6:00 P.M.

For comparison, six test runs were made on surface streets paralleling the Pasadena Freeway and its proposed extension via the Harbor Freeway. Seventy-three signals were encountered in a distance of 19.2 miles and an average speed of 20.8 miles was recorded. On two trips, at different locations, travel speed was reduced to 6 miles per hour for a distance of 1-1/2 miles.

Similar test runs paralleling the San Bernardino-Hollywood-Santa Monica Freeways for a distance of 30 miles showed an average speed of 23.2 miles. One hundred fifteen signals were encountered and speeds were reduced to less than 10 miles per hour in many places, the lowest recorded for any half mile being less than 5 miles per hour.

Summary of Physical Benefits

Summing up the physical benefits of the freeways as found in our 1951 study, it can be said that the freeway in comparison to a surface traffic artery, moves three times as much traffic, in one half the time, and with about one-fifth the risk of accident.

Direct Economic Benefits Resulting from Freeway Use

Report on "Economy of Freeways"

The high costs of right of way and construction began to lead to criticism of the expenditure of the vast sums of money allocated to the freeway projects. Even legislators called them "gold plated" and the tendency was to pull for the improvement of the surface arteries at considerably less first

cost. Having demonstrated physical benefits, we felt that it was time to measure the value of freeways in terms of money, to tell the motorist what he was getting for his money, and to gain and hold the much needed legislative and public support if our program was to continue. Actually instead of spending money in constructing freeways we were investing the motorists' money in a facility which returns some very substantial dividends.

This led to the publishing of our second report, "The Economy of Freeways," in 1953. In this report we made every effort to be conservative and to set up values which we could list as minimum benefits which could not well be challenged.

Operating Economies

By use of speed and delay studies and fuel savings tests, fully described in the Report, we established minimum savings to motorists using the freeways of 0.33¢ in gasoline savings and 0.24¢ in maintenance savings per vehicle mile. Other estimates in the Report are based on research and reasoning rather than on experiment. It has been encouraging that studies by other agencies, including the American Association of State Highway Officials in their report entitled "Road User Benefit Analyses for Highway Improvements" dated 1952, agree closely with our figures.

Accident Savings

The assignment of an economic value of accident savings was perhaps a new idea at the time of our Report. Our local freeways, while operating under the then unfavorable conditions of short lengths and overloading, have consistently maintained an accident record many times better than our best controlled and most efficient surface boulevards. This being true, it seems reasonable to include the reduction of accidents as a fixed characteristic of modern freeways and to enter it as an economic credit. We arrived at our value for accident savings by using records of the California Insurance Commission as to auto insurance premium costs, excluding theft, fire and comprehensive coverage, and from records of total gasoline consumption. On this basis we fixed an accident savings of 0.56¢ per vehicle mile due to use of the freeways.

The Value of Time

Time savings is an item of considerable and actual value, yet it appeared difficult to assign. It is clear that in the case of a commercial vehicle a saving in driver's wages and an increase in number of trips per day can be measured in money. It is not so easy to assign a value to pleasure time or to time spent in going back and forth to work.

Therefore since we have chosen to be very conservative, we entirely ignored the saving of time for pleasure vehicles even though this omission is probably debatable. We did, however, take the time value of trucks in the proportion trucks bear to the total traffic, and distributed this value among all vehicles to obtain an average value of 0.87¢ per mile time savings.

Summary of Report

Thus summing up operating, accident, and time savings, we established a total of 2¢ per mile as the minimum direct benefits to the motorists using the

freeways. Applying this to the conservative estimate of 776,100,000 vehicle miles of freeway travel over our 16.57 miles of freeways in operation for a 3 year period results in an indicated savings of $15,522,000. The original cost of the 16.57 miles of freeways under study was $42,027,000. If the savings could have been applied to the payment of the freeways, their original cost would have been amortized in about 3 years.

This checks closely with another later study compiled by the Automobile Club of Southern California entitled "An Appraisal of Freeways vs. Surface Streets in the Los Angeles Metropolitan Area" published in 1954. In this report, based on test runs by their engineers, it is estimated the Los Angeles motorists are saving $50,000,000 per year on a length of 45.1 miles of completed freeways estimated to cost $143 million. On this basis the freeways would also pay for themselves in less than 3 years.

The economic figures so developed by our Bureau, the Automobile Club, and the American Association of State Highway Officials, are most impressive and are receiving wide recognition and comment. These are clearly showing the enormous value of the freeways and that in the words generally attributed to Thomas H. MacDonald, former U. S. Commissioner of Public Roads, "We pay for good roads, whether we have them or not, but we pay more if we don't have them."

Indirect Benefits

Time does not permit a detailed discussion of the additional benefits of a freeway to the motorist and citizen. These cannot be easily evaluated in monetary terms, though none the less real. For example, the AASHO 1952 report previously referred to, while placing no value on traffic accident savings, has included a definite value for comfort and convenience. Other benefits are the stabilization or enhancement of property value, ability to properly plan for the land use and zoning of adjacent areas to provide the most effective development of the area, relief of existing overburdened surface arteries, doubling of the practical radius of real estate development on a travel time basis, increased access to recreational or cultural facilities, increased mobility in times of disaster emergencies, increased tourist travel, and all of the other well known advantages in betterment of transportation. The benefits to the large amounts of traffic continuing to use formerly heavily congested surface arteries after the freeway system is built are not usually visualized. Before and after surveys have shown that removal of through traffic from surface arteries to the freeways benefits community business, property values, surface travel time, and safety on the surface system. In addition, the intended use of the freeways by express buses will greatly increase the economic value of the freeways to the general public, of which the motorists comprise a large part. The monetary value of these benefits could well amount to huge sums, since they are so vitally integrated with the general financial health and progress of the region. It should be borne in mind that conversely to the benefits accruing from having good transportation, if there were no freeways there would be the losses that the region would suffer from not having them. An article entitled "Revealing Direct Benefits from Freeway Development" in "CALIFORNIA HIGHWAYS AND PUBLIC WORKS" July-August 1955, documents directly many of the demonstrated benefits of the freeways constructed to date in the Los Angeles Area.

It can be clearly observed that the rate of growth, both residential and

industrial, has been greatly spurred in the areas tributary to such freeways as the San Bernardino and Santa Ana Freeways. When planned, these freeways traversed lands almost wholly devoted to agriculture. These areas are now experiencing a residential and industrial development of amazing proportions.

Attention can only be directed to before and after construction studies which have been made by the California Division of Highways of the effects of a freeway on the districts traversed. These studies have been publicized from time to time over the past several years in the "CALIFORNIA HIGHWAYS AND PUBLIC WORKS." They supply authentic well documented evidence of the direct benefits that have accrued to various districts of the State of California from the freeways serving them.

Evaluating the Benefits of a Freeway System

General

It seemed desirable to carry our studies somewhat farther in trying to establish the benefits of a freeway system as compared to the abstract and general benefits derived in "The Economy of Freeways." This we have done in our latest report, "A Study of Freeway System Benefits," dated September 1954.

It appears without question that the value of a freeway increases as it becomes integrated into a freeway system. Temporary terminii with their resultant bottlenecks are eliminated and a more flexible use of the freeways to reduce surface artery congestion is made possible.

Furthermore it is difficult to use a single freeway most effectively for express bus service. Express bus operation is dependent on surface feeder lines which cannot be effectively established until express bus service is available on an integrated freeway system.

Failure to construct the freeway units of a system fast enough has also resulted in overloading the freeways which have been completed, thus reducing their efficiency. For example, the Hollywood Freeway is handling presently 183,000 cars per day. This is clearly due to an undue diversion of traffic from paralleling surface arteries. The fact that 40% and 48% of the traffic on Sunset Boulevard and Temple Street respectively was diverted is understandable, for these streets closely parallel the freeway. But when traffic was reduced 20% to 30% on streets such as Olympic Boulevard and Riverside Drive, as much as 2 miles from the freeway, it is indicative of the need of the Olympic and Golden State Freeways, which parallel these streets. While the Hollywood Freeway carries this heavy load amazingly well, with peak hour flows in one direction on a four lane roadway as high as 8800 cars per hour, it does so at reduced speeds and potential congestion which can be caused by the slightest accident or emergency.

There is little question that this or any area would be most benefitted if the proposed freeway system could be built as rapidly as possible—actually immediately. Present funds in this area, provided on a pay-as-you-go basis, only permit the construction of freeways as rapidly as funds become available. While our freeways are now being constructed at the rate of about $65,000,000 per year, this amount is not adequate to provide the freeways as rapidly as they are needed. In fact we are far behind in supplying the freeways demanded by the present traffic flows.

Two major points are then to be considered:

1) If we must continue to construct the freeway system on the basis of one unit at a time as funds permit, we should build those first which will give the greatest return for the money invested; and

2) If freeway benefits are as great as is shown by our analyses, should we not attempt to expedite their early construction by a method of financing other than or supplemental to the pay-as-you-go method?

Determination of Freeway Priorities

In line with the first point discussed above, it seemed necessary to set up a reliable yardstick whereby a ratio between freeway costs and benefits for different conditions of traffic demand, terrain and local development can be determined. This cost-benefit ratio has in itself two purposes. One is to determine if a freeway is justified as against the improvement or reconstruction of surface routes. The other is to permit a proper comparison of one freeway route with another, or to establish the correct priority for constructing the individual freeways of a planned system.

In the case of justifying the first cost of a freeway it is desirable to be extremely conservative, as we have been in our report "The Economy of Freeways," avoiding the use of any controversial values. However, in comparing the value of two proposed freeways, an important factor is found to be the proportion of truck traffic to the estimated total traffic. Now if a time value is used for trucks only, the comparison is warped in favor of the route that will carry the greatest number of trucks, even when the highest demand and the greatest traffic relief favors another route. When a motorist is willing to drive more miles to save time, or to pay a toll for the same purpose, some measure is given of the value he himself puts on his time.

Therefore in our latest Report we have set up values for passenger car benefits, with and without time savings, and benefits for pickups and trucks using the freeways. Average benefits as computed for a large mileage of our proposed freeways are as shown in the following table.

AVERAGE BENEFIT PER VEHICLE MILE

	Average Annual veh.-Miles millions	Average Annual Benefit $ millions	Average Benefit per Veh.-Mile cents
Passenger cars with time value	3726.8	138.9	3.73
Without time value	3726.8	41.6	1.12
Trucks	257.8	25.6	9.93
Pickups	208.2	9.7	4.66
Weighted Avg. Vehicle			4.16

In computing truck benefits for the individual freeway routes we have used the California Public Utility Commission's constructive mileage ratios. This is a mileage used for rate-making purposes in the transportation of property. It is designed to compensate for adverse physical conditions of the highway,

such as grades, poor roadway surfaces, curvature, traffic signals, congestion, and other factors which add to the cost of truck operation over and above the normal expense.

In order to calculate the benefits of a particular freeway route it is necessary to estimate the anticipated traffic volumes at the time the freeway is put into operation and the anticipated traffic growth in 20 years. These volumes must be broken down into percentages of passenger car, pickup and truck traffic. From these volumes and from known lengths of the freeways an estimate of vehicle miles of travel can be determined. From the percentages and constructive mileage ratios a weighted average benefit per vehicle mile can be determined. From these two factors the total estimated benefits can be computed.

Estimates of the first costs of the freeway units can be made by standardized methods of computing right of way and construction costs.

Thus a measure of the value of the freeway is determined which can be compared to the value of the old or surface route, and by relating costs to benefits a cost/benefit ratio can be obtained which is the measure of the value of this freeway as compared to other freeway routes, thus a measure of the relative value or priority of the individual freeway routes.

In order to demonstrate the above method and its results, computations were made of the cost/benefit ratios of four typical proposed freeway units of our freeway plan. Two of these routes, the Alamitos and Golden State Freeways, will carry heavy percentages of trucks and pickups and thus were found to have cost/benefit ratios of 4.5 and 3.4 respectively. One of the routes, Olympic Freeway (shown on the maps as Venice Freeway), will carry an exceedingly heavy volume of passenger cars, with a low percentage of trucks and pickups. However, the cost/benefit ratio for this condition also was found to be 3.4, equal to that of the Golden State Freeway with its heavy truck and pickup use. The fourth of the routes compared, the Colorado Freeway, shows a smaller total volume of traffic and a relatively low percentage of trucks and pickups, resulting in a cost/benefit ratio of 9.5.

Demonstrating Benefits from a Completed System of Freeways

As previously indicated, the present approved Master Plan of Freeways includes a total of 620 miles, including those presently built, under construction, or authorized. To demonstrate the tremendous benefits of an even partially completed system of freeways, a study was made of a group of representative freeway projects in the Los Angeles Metropolitan Area, not including those projects already completed or budgeted. These future projects totaled 185 miles, which, when added to the freeways now assured, would bring the total to roughly one-half of the system contemplated by the Master Plan. The estimated cost of the 185 miles of freeways was determined to be $775,000,000.

Reduction of annual benefits to a present value, with interest at 3%, compounded annually, indicates that benefits would equal the initial cost of the 185 miles in less than 7 years (passenger car time savings included) or 15 years (if passenger car time savings are not included). In addition, benefits on this system amount to more than 3 times the original cost in 20 years with interest at 3% and passenger car time savings included.

Consideration of such facts as have been demonstrated by our findings for the Los Angeles Freeway System, and which without question are equally true

for any freeway type highway or system wherever properly proposed, cannot but raise a question as to the adequacy of our present financing methods. These facts provide justification for consideration of bond financing methods, and point to the need for such programs as the expedited Federal Aid Highway Program proposed by the Administration in the last session of Congress.

To justify such an expedited freeway construction program it is only further necessary to demonstrate that (1) design and planning can be sufficiently expedited, (2) that the expedited purchase and clearing of rights of way can be accomplished, and (3) that contractors have or can supply the needed construction equipment and services to complete the accelerated program. It has been clearly shown by proper authorities that each of these requirements can be met.

CONCLUSION

It is believed that this paper has demonstrated the great value of the freeway or controlled access highway, not only directly to the highway user, but to the community as a whole. The dividends are great. The planning and construction of freeways should therefore be expedited to the fullest extent by an energetic and courageous assault on this outstanding local and national need. We as engineers are privileged to fill a leading part in this effort.

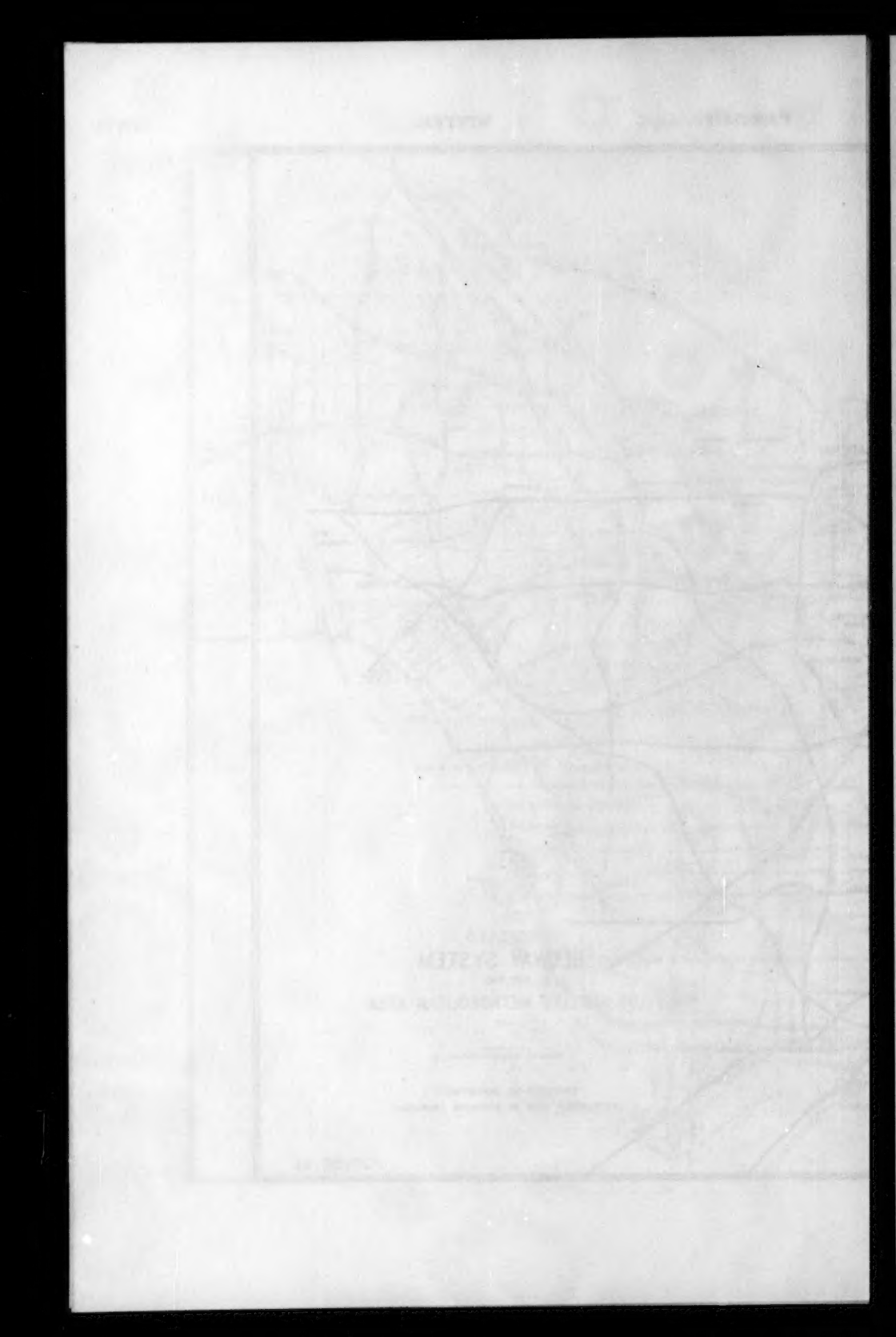
VENTURA
LOS ANGELES
ORANGE
Pacific Ocean
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
DISTRICT VII
FREEWAYS
Legend
COMPLETED OR UNDER CONSTRUCTION
BUDGETED
UNDER FREEWAY RESOLUTION
Scale in Miles
0 2 4 6 10
JULY 1, 1955

FIGURE I

LOS ANGELES COUNTY
VENTURA COUNTY
SAN FERNANDO
FOOTHILL FREEWAY
GOLDEN STATE FREEWAY
WHITNALL FREEWAY
VENTURA FREEWAY
HOLLYWOOD FREEWAY
SAN DIEGO FREEWAY
RESEDA
BURBANK
GLENDALE
PASADENA FREEWAY
HOLLYWOOD
BEVERLY HILLS
SANTA MONICA FREEWAY
SANTA MONICA
VENICE
CULVER CITY
SAN DIEGO FREEWAY
MARINA FREEWAY
SLAUSON
VERNON
MAYWOOD
HUNTINGTON PARK
PACIFIC OCEAN
PLAYA DEL REY
INGLEWOOD
SOUTHGATE
LYNWOOD
EL SEGUNDO
HAWTHORNE
MANHATTAN BEACH
COMPTON
ARTESIA
HERMOSA BEACH
REDONDO BEACH
TORRANCE
HARBOR FREEWAY
PACIFIC COAST
PALOS VERDES ESTATES
WILMINGTON
LONG BEACH
SAN PEDRO
LOS ANGELES-LONG BEACH HARBOR

SIERRA MADRE
MONROVIA
SAN MARINO
ARCADIA
AZUSA
GLENDORA
SAN GABRIEL
LA VERNE
CLAREMONT
COVINA
EL MONTE
SAN BERNARDINO
POMONA
WEST COVINA
MONTEBELLO
PUENTE
WHITTIER
SAN BERNARDINO COUNTY
LOS ANGELES COUNTY
ORANGE COUNTY
DOWNEY
SANTA FE SPRINGS
BREA
NORWALK
FULLERTON
BUENA PARK
SAN DIEGO FREEWAY
FREEWAY
ROUTE 72
PROPOSED
FREEWAY SYSTEM
FOR THE
LOS ANGELES METROPOLITAN AREA
1955
ENGINEERING DEPARTMENT
AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA

FIGURE II



JOURNAL

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

CONTROL OF HIGHWAY ACCESS: USER BENEFITS IN CALIFORNIA

Ralph A. Moyer,[1] A.M. ASCE
(Proc. Paper 875)

FOREWORD

The limitation or control of access to public highways is probably the major feature distinguishing modern highways from those built in earlier periods. True enough, the separation of grades at intersections, the dividing of highways to separate traffic moving in opposing directions and the provision for extra lanes to accommodate heavy traffic flows, are also embodied in the design of highways currently being constructed to provide for the ever-increasing numbers of moving motor vehicles. However, it is believed that the denial of abutters' rights to enter at will upon public highways is the fundamental change in the concept of a modern highway. This concept has been slow to evolve and a number of the American states do not yet have legal authority to construct highways which include access prohibitions. Other states have had such favorable acceptance of this principle, that they exercise access control whenever land is purchased for highway relocations. A few states go further and curtail roadside development by declaring certain existing highways to be freeways.

The purpose in arranging the Symposium was to broaden knowledge of the subject and to encourage greater use of this means of reducing the obsolescence of the highways needed for our motor vehicle economy.

SYNOPSIS

In this paper an analysis is given of the highway user benefits resulting from the early completion of the freeways with full control of access which comprise the 1912 miles of rural and urban highways on the Interstate System in California. This analysis is an important consideration in determining the economic justification for the expenditure of $2.3 billion for the completion of the Interstate System in California over a ten year period.

The analysis shows that the estimated user benefits in the first ten years

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amounted to $1 billion which is an amount greater than the total interest for 30 years on the investment. The estimated user benefits over a 30-year period amounted to almost $8 billion which is more than double the total interest and principal which the analysis shows would be required to finance the Interstate System in California.

INTRODUCTION

Control of access is a major requirement in the construction of the freeways on the Interstate System in California. It is the primary factor which makes it possible for these freeways to carry the exceptionally large traffic volumes which they are called upon to carry and at the same time provide the large savings and benefits to users which fully justify the high right-of-way costs and construction costs of the freeways on the Interstate System.

In this paper an analysis is given of highway user benefits resulting from the early completion of the Interstate System in California. This analysis gives an indication of the magnitude of the funds involved in the construction of freeways and in the operation of traffic on these freeways. It is a topic of major importance in an evaluation of the widely discussed Eisenhower "Grand Plan" for an accelerated, integrated, national highway program.

During the past year and a half, the Eisenhower plan has stimulated greater interest in a national highway program than any previous plan in the history of highway development in the United States. It is a bold plan which encompasses all of the Nation's present highway needs and the projected needs during the next three decades. The plan calls for a total expenditure of $101 billion during the next ten years to improve the roads and streets in all of the road systems in the country. Top priority in the plan is given to the modernization of the 40,000 mile National System of Interstate Highways, which the Eisenhower plan proposes should be financed largely with federal funds.

While many highway authorities have doubted if the Federal Government and the States can agree on a plan to finance a $101 billion program, no one denies that the highway situation is critical—so critical, in fact, that only a bold plan such as the one proposed by the President offers hope of solving the nation's highway traffic problems in this generation. It is important that all factual data pertaining to the financing and the economic justification for embarking on such a tremendous public works program be fully explored before Congress and the states reach a decision either for or against. It is for this reason that the papers being presented in this Symposium take on special significance.

While the analysis of highway user benefits is an important factor in determining the economic justification for the expenditure of highway funds, it is only a part of a much larger study which should be made in developing a sound highway program for each state and for the Nation. I refer to the state-wide highway planning surveys and the engineering investigations in which practically all of the 48 states have been engaged in cooperation with the Bureau of Public Roads since 1935. The great value and importance of these surveys and investigations in providing the basic facts for the formulation and evaluation of the President's program are not generally understood. It seems appropriate at this point, therefore, to relate the user-benefit analysis to the broader features of the highway planning surveys, and to review briefly the development and functions performed by the state-wide highway planning surveys.

Importance and Significance of the State-Wide Highway Planning Surveys

The large-scale highway program proposed by the President actually represents the culmination of twenty years of intensive fact-finding through the state-wide planning surveys and engineering investigations. These surveys and engineering investigations were started under the provisions of the Federal Act of 1934, known as the Hayden-Cartwright Act, which authorized the expenditure of not to exceed 1-1/2 percent of the amount of Federal-Aid highway funds apportioned for any year to any state for making highway planning surveys and engineering investigations.

At the time of their undertaking, the highway planning surveys were described as follows:

"They consist of a number of related studies that seek to determine the present state of the whole rural highway system; to rate the service rendered by the numerous parts; to prepare the way for a selection of that part of the whole system which, by reason of its relative importance and absolute utility, so far as we may now see, merits inclusion in future improvement plans; to assemble the facts necessary for an estimate of the ultimate cost of owning and maintaining the economically necessary improved system; all to the end that a definite economically and socially defensible, integrated highway improvement program may be established and the future of highway transportation may be protected from the hazards inherent in short-sighted and shifting public policy."(1)

It is significant that the state-wide highway planning surveys, which were started in the depression years of the nineteen thirties, have been conducted in all 48 states during the past 20 years in cooperation with the Bureau of Public Roads in accordance with the broad policy as outlined above and have yielded factual data of immeasurable value. To be sure there have been many important changes in the pattern of highway transportation since the surveys were started in 1935 but the full impact and significance of these changes can now be determined only because the basic traffic and highway fact data were collected and made the subject of careful study during the past 20 years.

The Interstate System in California

One of the important results of the planning surveys was the establishing of the 40,000-mile National System of Interstate Highways. This system, traffic surveys show, carries more than a seventh of all highway traffic, although it embraces only 1.2 percent of the nation's total road mileage. In Table 1, mileage and traffic data for the California Interstate System as of 1954 are given. It is interesting to note that the urban mileage, amounting to 245.5 miles, or one-eighth the total mileage on the Interstate System, carried one-third of all traffic on the California Interstate System and that the traffic on the 1912.6 miles of the Interstate System comprised about one-seventh of all highway traffic on all the streets and highways in California.

The costs of a 10-year program for constructing the California Interstate System to full freeway standards and to specifications adequate for traffic 20 years hence, according to estimates prepared by the California Division of Highways, are given in Table 2. It is significant that for the rural portion of the California Interstate System the right-of-way costs are about one-fifth the total cost of the rural portion whereas for the urban portion, the right-of-way costs are more than one-half the total cost of the urban portion. Also the

TABLE 1 — MILEAGE AND TRAFFIC DATA FOR THE CALIFORNIA INTERSTATE SYSTEM

Classification	Miles in 1954	Traffic in 1953	
		Average Daily Vehicle-Miles	Annual Vehicle-Miles
Rural Interstate	1667.1	12,503,000	4,564,000,000
Urban Interstate	245.5	6,554,000	2,393,000,000
Total	1912.6	19,057,000	6,957,000,000
Passenger Car Traffic	= 88% (includes panels, pick-ups and 4-tired commercial delivery vehicles)		
Truck Traffic	= 12% (includes buses)		

total cost of the urban portion is about 3 times the total cost of the rural portion. The rural portion averages $355,200 per mile while the urban portion averages $7,044,000 per mile. The total cost for a 10-year program for right-of-way and construction of the California Interstate System is estimated at $2,321,553,000 or very nearly 10 percent of the estimated cost for the National System of Interstate Highways in all 48 states.

TABLE 2 — COSTS FOR RIGHT OF WAY AND CONSTRUCTION OF THE CALIFORNIA INTERSTATE SYSTEM IN A 10-YEAR PROGRAM

Item	Rural	Urban
Right-of-Way Cost 1955-1964	$124,807,000	$1,022,180,000
Total Cost 10-yr Program	$592,318,000	$1,729,235,000
Total Cost per Mile	$ 355,200	$ 7,044,000
Total Cost 10-yr Program - Rural and Urban	$2,321,553,000	

Analysis of Highway User Benefits

In making this study, highway user benefit data from two outstanding reports on the subject are used together with other data developed by the writer in his research studies at Iowa State College and at the Institute of Transportation and Traffic Engineering. One of the best references in user benefit analysis is the report by the Committee on Planning and Design Policies of the American Association of State Highway Officials.(2) Another reference especially useful in this study is the report by the City of Los Angeles Engineering Department on a study of freeway benefits.(3) Both these reports deal primarily with an analysis of the benefits in the operation of passenger cars; they provide only limited data about commercial vehicles—buses and trucks in the various weight classifications—which today constitute such an important part of our traffic stream. Buses and trucks greatly complicate

the study of user benefits, because they strongly influence such factors in vehicle operation as speeds, time savings, accidents, and costs. While the use of ratios in relating truck and bus operating costs to passenger car operating costs provides the best solution now available, it is far from accurate, especially for user benefit analysis of individual projects where the effects of grades, traffic stops, time savings, and accident savings may vary greatly depending upon local conditions. The importance of developing more reliable and complete information in regard to operating costs under many different conditions for all of the major classes of commercial vehicles is apparent when we recognize that approximations, when applied to the benefits predicted for a project life of 20 to 30 years, may lead to errors of millions of dollars on a single major project.

It is, no doubt, true that the need for highway improvements and the benefits derived from them have up to now been obviously so great that highway engineers have seldom considered it necessary to make careful analyses of user benefits and to demonstrate the economic justification for the expenditure of public funds for building roads and streets. Today, however, when we are considering embarking on a $101 billion program, the responsibility of the engineer assumes proportions which far surpass his responsibility in the past. It is now becoming apparent that if this program is adopted, a fixed pattern of transportation, notably in metropolitan areas, will probably be established for the next 40 or 50 years. The investment of $100 billion in our highway plant will be so costly and will bulk so large physically, that it will possess a degree of permanence which may be our greatest threat to progress in planning future transportation facilities, especially for our large metropolitan areas. It certainly behooves highway engineers today to look far into the future and to plan wisely, not only by using the facts furnished by the planning surveys but also by developing new ones.

In my opinion highway engineers might profit greatly by carefully considering certain practices recommended by the Subcommittee on Benefits and Costs, of the U. S. Federal Inter-Agency River Basin Committee.(4) The Subcommittee reviewed the benefit-cost practices currently in use by the various Federal agencies and formulated mutually acceptable principles and procedures for determining benefits and costs for all water resources projects in the United States.

The purpose of the economic analyses procedures set forth by the Subcommittee was for the determination and evaluation of the most effective use of the nation's economic resources in developing and programming water resource projects. The comprehensive nature of the proposed economic analyses procedures is indicated by the following partial list of items discussed in the report.

1) Standards for measurement of benefits and costs.
2) Classification into primary (direct) and secondary (indirect or induced) benefits and costs.
3) Effect of price levels, present and future.
4) Interest and discount rates and risk allowances.
5) Period of analysis; project life and economic life.
6) Adjustment for varying levels of employment and economic activity.
7) Effect on land values.
8) Effect on production,—on the amount and value of goods and services.
9) Consequential damages.
10) Treatment of taxes.

Some of the items listed above will be covered by other papers in this Symposium. It is evident from the discussions in these papers that some of our highway departments are giving consideration to the need for economic analyses of highway projects. However, the practices in regard to procedures in making economic analyses vary greatly in the different states and too frequently no economic analyses are made. Or if they are made, they are very sketchy and over-simplified.

It should be evident in the light of the above discussion, that the following analysis of benefits for the Interstate System in California covers only two major items: the user benefits and the project costs. Also, the analysis on a system basis, rather than on a project by project basis, may over-simplify the solution. The solution given does, however, indicate the magnitude and importance of user benefits in determining the economic justification for a program in a given state. And it may stimulate greater interest in developing standard procedures and the necessary factual data elsewhere.

User Benefits on the Urban Interstate System

User benefits on urban freeways consist of savings in time costs, in vehicle operating costs (fuel, oil, tires and repair costs), and in traffic-accident costs. In this analysis, it is assumed that full freeways will be built on all portions of the Urban Interstate System in California which will provide full control of access, complete elimination of intersections at grade and of vehicular traffic conflicts, and elimination of pedestrian traffic. Geometric design features will be used to expedite the safe movement of the large volumes of through-traffic which are characteristic of arterial highways in the urban areas of California.

The user benefits on the Urban Interstate System adopted for this study are:

Time-cost savings

$1.35 per hour for passenger cars
$3.00 per hour for trucks and buses

- - - - - - - - - - - - - - - -

2.61 cents per vehicle-mile for cars
3.18 cents per vehicle-mile for trucks and buses
2.68 cents per vehicle-mile for all vehicles

Vehicle-operating-cost savings

0.52 cents per vehicle-mile for passenger cars
3.54 cents per vehicle-mile for trucks and buses
0.88 cents per vehicle-mile for all vehicles

Accident-cost savings

0.6 cents per vehicle-mile for all vehicles

Weighted average benefit for all vehicles using the urban Interstate System

4.16 cents per vehicle-mile

The weighted average benefit on the Urban Interstate System of 4.16 cents per vehicle mile represents the average benefit or savings resulting from operation of cars, trucks, and buses on full freeways instead of on the state highway routes on major city streets (where there are many intersections at grade controlled with traffic signals which require frequent stops).

The time-cost savings of $1.35 per hour for passenger cars and $3.00 per hour for trucks and buses are the values used by the California Division of Highways and the City of Los Angeles Engineering Department in their highway user benefit studies. The AASHO Committee on Planning and Design Policies also adopted a time value of $1.35 per hour for passenger cars as "representative of current opinion for a logical and practical value."

It is, of course, difficult to establish a value of time for passenger cars, but there are at least three considerations which form the principal arguments for assigning one. They are: (1) The highway planning surveys in California and in other states have shown that 60 to 70 percent of the total travel by passenger car is on trips for the purpose of earning a living. (2) It has been established in many studies that the most reliable factor to be considered in assigning traffic to freeways is the time-saving factor; more than half the trips on the freeways in these studies show a saving in time when compared with trips which could be made by the same cars using the nearest alternate route. (3) Motorists have shown a willingness to pay toll to travel on turnpikes where the principal user benefit is the time saving benefit; recent studies by the Bureau of Public Roads have shown that a time-saving advantage is shown in more than 80 percent of the trips by passenger cars using the Maine and the Pennsylvania Turnpikes.(5)(6)

The vehicle-operating-cost savings adopted for this study are the same as those used by the City of Los Angeles Engineering Department in their studies of freeway benefits. The savings in operating cost are due primarily to the elimination of traffic stops on the freeways which permits all classes of vehicles to operate on the freeways at uniform speeds. The operating costs for various types of vehicles can be measured for any given project and are therefore costs which can be established with a greater degree of accuracy than the time-cost and accident-cost savings. The operating-cost savings adopted for this study are average values considered to be representative of the benefits in operating cost provided by full freeways in urban areas.

The accident-cost saving of 0.6 cents per vehicle-mile is the same value as that used in the Los Angeles freeway benefit study by the Los Angeles Engineering Department although a slightly different procedure was used in computing the accident-cost saving for this study.

The California highway safety record on full freeways from 1941 to 1954 has been outstanding and fully justifies the City of Los Angeles accident-cost saving of 0.6 cents per vehicle-mile. In Table 3 the traffic and accident data on state highways in California are given for 1954 together with the traffic and accident data on full freeways for the fourteen year period in which the full freeways have been in operation. The low fatality rate on the full freeways provides the best indication of the accident-cost saving provided by full freeways.

The City of Los Angeles computed the average accident cost per vehicle mile on the basis of the California Insurance Commission reports of auto insurance premium costs, excluding theft, fire and comprehensive coverage, to be 0.7 cents per vehicle-mile. Each year the National Safety Council publishes an estimate of the annual cost of highway accidents in Accident Facts.

TABLE 3 — 1954 TRAFFIC AND ACCIDENT DATA ON RURAL STATE HIGHWAYS AND ON RURAL AND URBAN FREEWAYS IN CALIFORNIA

Source: California Division of Highways Traffic Section Accident Reports

Number of Lanes	Miles	Average Daily Traffic	Accidents Per MVM*	Fatal & Injury Acc. Per MVM*	Fatalities Per 100 MVM*
2	10,846	2,359	2.21	0.98	9.49
3	143	12,300	2.65	1.03	9.68
4 Undivided	181	21,301	3.54	1.29	6.47
4 Divided	220	15,712	3.11	1.16	8.18
4 Divided Expressways	667	11,723	1.71	0.74	6.45
Full Freeways - 1954 Rural and Urban	131	45,194	1.27	0.53	1.92
Total Traffic on Freeways		2,161 MVM*			
Full Freeways 1941-1954 Rural and Urban	Mi. Yrs. 421	41,822	1.37	0.58	2.15
Total Traffic on Freeways		6,420 MVM*			

*Million Vehicle Miles

By using the Bureau of Public Roads estimate of total highway travel per year published in their annual Highway Statistics report and the National Safety Council annual cost of highway accidents, a computed average accident-cost of about 0.7 cents per vehicle-mile is obtained which is the same as that obtained in the City of Los Angeles computations.

The City of Los Angeles studies of traffic accidents showed that travel on freeways in Los Angeles involves only one-fifth of the accident risk that prevails on typical surface routes. With four-fifths of the accident risk removed, the Los Angeles Engineering Department computed the accident-cost saving on the freeways to be four-fifths of 0.7 cents per vehicle-mile or 0.6 cents per vehicle-mile.

In this study, the accident records of the California Division of Highways were used in arriving at the value of 0.6 cents per vehicle-mile for accident-cost savings. The best indicator of accident costs is the fatality record. For the rural State highways in California, from 1949 to 1954, the fatality rate was 9.6 per 100 million vehicle-miles (MVM) and on the major city streets on the State Highway System, it exceeded 10.0 per 100 MVM. The average fatality rate on all streets and highways in California was 7.0 per 100 MVM. On the full freeways of California over a 14-year period, the fatality rate as given in Table 3 was 2.15 per 100 MVM. On the basis of these data, a conservative estimate of 0.9 cents per vehicle-mile is used in this study for the

accident costs on the major city surface streets on the Interstate System and 0.3 cents per vehicle-mile on full freeways. The difference in these two costs amounting to 0.6 cents per vehicle-mile represents a conservative estimate of the saving in accident costs provided by full freeways in California.

User Benefits on the Rural Interstate System

The highway user benefits on the Rural Interstate System in California consist of savings in time costs, in vehicle operating costs, and in traffic accident costs which are the same costs as were used on the Urban Interstate System but on a greatly reduced basis. Not all the mileage on the Rural Interstate System will consist of full freeways, since the traffic volumes on a part of this mileage will not warrant the construction of the full freeway type facility. The present highways on the Rural Interstate System consist of two-lane, three-lane and a considerable mileage of the four-lane divided and undivided highway and expressway classifications listed in Table 3. A large part of the present mileage consists of freeways with partial control of access but with intersections-at-grade. There are fewer traffic stops, lower traffic volumes, there is less congestion, and the speeds on the present rural Interstate highways are higher than on the urban Interstate System. All these factors contribute to a reduction in the user benefits for the Rural Interstate System when compared with the benefits listed above for the Urban Interstate System.

The user benefits on the Rural Interstate System adopted for this study are:

Time-cost savings

$1.35 per hour for passenger cars
$3.00 per hour for trucks and buses

- - - - - - - - - - - - - - - -

0.75 cents per vehicle-mile for cars
1.9 cents per vehicle-mile for trucks and buses

Increase in vehicle-operating-costs (No savings)

0.75 cents per vehicle-mile for cars
0 cents per vehicle-mile for trucks and buses

Accident-cost savings

0.6 cents per vehicle-mile for all vehicles

Weighted Average Benefit for All Vehicles Using the Rural Interstate System

0.83 cents per vehicle-mile

On the California Rural Interstate System, it is estimated that the average speed of passenger cars will be about 60 mph, based on speed surveys on existing freeways in rural sections. The average speeds on the existing rural Interstate highways range from 40 to 50 mph. While the proposed Rural Interstate System will provide improved alignment, reduction of grades, and elimination of traffic stops, the most important improvements of this type have already been made on more than 1400 miles of the rural portion of the California Interstate System. Test runs with passenger cars on a considerable mileage of the Rural Interstate System have indicated that vehicle operating costs at the lower speeds of 40 to 50 mph on the existing Interstate

mileage will average about 1/2¢ to 1¢ per mile less than when operating at 60 mph average speed on the rural freeways. Using the AASHO time-saving cost of $1.35 per hour for passenger cars results in a time saving of 3/4¢ per mile driving at a 60-mph average speed instead of a 45-mph average speed. Thus, in this study it is assumed that the time saving benefits on the rural freeways are offset almost exactly by the increased vehicle operating costs and that the only saving or benefit to passenger cars is the accident-cost saving which the California accident statistics indicate should be about the same on rural freeways on the Interstate System as on the urban freeways, or 0.6¢ per vehicle-mile for both cars and trucks.

The benefits for trucks on the Rural Interstate are also greatly reduced as compared to the benefits on the Urban Interstate System. The reduction in grades and curvature and the elimination of traffic stops will provide greater advantages in reduced operating costs for trucks than for cars. The increased speed of trucks on the full freeways on the Rural Interstate System will increase the fuel, oil, and tire costs, but on the basis of the test data now available, the savings in operating costs for trucks provided by the highway improvements on the Rural Interstate System will just about equal the increased operating costs due to the operation at the higher speeds on the full freeways.

The time-cost saving for trucks was computed using an average truck speed of 35 mph on the existing highways and 45 mph on the full freeways. Using truck time costs of $3.00 per hour, this will result in a time-cost saving for trucks of 1.9¢ per vehicle-mile.

The accident-cost saving for trucks on the Rural Interstate System is assumed to be the same as on the Urban Interstate, or 0.6¢ per vehicle-mile. The total benefit for trucks on the Rural Interstate, therefore, totals 2.5¢ per vehicle-mile.

While the speed characteristics of bus traffic are more nearly the same as for passenger car traffic on the Rural Interstate System, the vehicle operating cost characteristics for buses are somewhat similar to the truck operating costs. In this study the costs for bus traffic which comprises less than one percent of the total traffic on the Interstate System, are assumed to be the same as for truck traffic. With truck and bus traffic comprising 12 percent of the total traffic on the Rural Interstate System, the Weighted Average Benefit per vehicle-mile for all traffic on the Rural Interstate System will then amount to 0.83 cents per vehicle-mile which is only about one-fifth of the Urban Interstate System benefit of 4.16 cents per vehicle-mile obtained in this study.

Traffic on the Interstate System

Zettel[7] has estimated annual increases of 3.8 percent per year in California motor vehicle registration and 4.5 percent per year in California motor-vehicle travel. An average rate of 4.0 percent per year is used in this study as a conservative estimate of the traffic increase during the next 30 years on the California Interstate System.

Using the 1953 traffic count on the Interstate System as the basis for computing future traffic, a 4 percent increase per year will yield an expansion factor of 1.601 for 1965 traffic, 2.3699 for 1975 traffic, and 3.5081 for 1985 traffic. The estimated traffic volumes on the California Interstate System for 1955, 1965, 1975 and 1985 are given in Table 4. These traffic volumes

TABLE 4 — ESTIMATED ANNUAL TRAFFIC VOLUMES ON THE CALIFORNIA INTERSTATE SYSTEM FOR 1955, 1965, 1975 and 1985

Classification	Estimated Annual Traffic Volumes in 1,000,000 Vehicle-Miles			
	1955	1965	1975	1985
Rural	4,936	7,307	10,816	16,011
Urban	2,588	3,831	5,671	8,395
Total	7,524	11,138	16,487	24,406

are believed to be conservative since careful studies have not been made to determine the extent to which new traffic will be generated or induced by an accelerated program of construction on the Interstate System.

With an expansion factor of 3.5 for 1985 traffic and projected traffic volumes on the Urban Interstate System exceeding 8 billion vehicle-miles, the question may be raised as to whether urban freeways can be built in a city such as Los Angeles to carry the projected traffic volumes in 1985 when it is a well-known fact that the present freeways in Los Angeles are overcrowded during the peak hours. The answer to that question is that at the present time only about one-eighth of the freeway mileage planned for the Los Angeles area has been built. If the remaining mileage of planned urban freeways in the Los Angeles area could be built as a part of an accelerated program, much of the congestion on the present freeways could be eliminated. At the same time, with projected traffic volumes on the Urban Interstate System 3-1/2 times the present volumes, the pressures for developing a satisfactory solution to the mass transportation problems in large metropolitan areas will be so great that a solution may be forthcoming. Certainly, it will not be possible to expand the space occupied by urban freeways indefinitely. More efficient use may have to be made of the freeways as presently planned, by moving more people instead of more cars. In this paper, no consideration is given to an analysis of user benefits beyond 1985, but it is evident from the above discussion that long-range studies should be started in the near future of the transportation requirements and of the type of facilities which should be developed after all the space which may reasonably be allotted to freeways is occupied.

Summary of User Benefits on the Interstate System

In computing the user benefits on the Interstate System which are given in summary form in Table 5, it was assumed that the program of improvement would be completed in 10 years and would proceed at a uniform rate over the 10-year period. It was also assumed that the user benefits would be maintained at about the same rate over the 30-year period in which traffic will be expected to pay for the entire cost of the freeways built during the 10-year period. The above assumptions appear to be reasonable and proper for the purpose of this analysis and when viewed on the basis of the highway operating cost trends of the past 10 years.

In Table 5 the user benefits are given for each 10-year period and for the

TABLE 5 — COMPUTED USER BENEFITS ON THE CALIFORNIA INTERSTATE SYSTEM BASED ON A 10-YEAR CONSTRUCTION PROGRAM, 1956-1965

Part of System	First 10-yr Benefits 1956-1965	Second 10-yr Benefits 1966-1975	Third 10-yr Benefits 1976-1985	Total 30-yr Benefits 1956-1985
Rural	$ 298,700,000	$ 757,200,000	$1,121,000,000	$2,176,900,000
Urban	$ 784,800,000	$1,990,000,000	$2,945,000,000	$5,719,800,000
Total System	$1,083,500,000	$2,747,200,000	$4,066,000,000	$7,896,700,000

entire 30-year period from 1956 to 1985. It was assumed that if the construction of the Interstate System would be completed in a 10-year period, the maximum benefit would accrue over the entire system only during the 11th year and the period following the 11th year. The benefit during the first 10-year period was computed on a proportionate basis in terms of the percentage of the system or the percentage of total mileage completed during each year and using the benefited traffic volume estimated for that year. Thus, by the end of the 5th year, one-half the system is assumed completed, but the benefits for the 5th year would amount to the average percent of the system improved for the 5th year, or 45 percent of the benefit for a fully completed Interstate System.

Traffic to which benefits are related in the first 10-year period has been considered in this study as the average of the traffic in the first and last years of that 10-year period. The 10-year benefits so obtained are slightly higher than would be obtained by totaling the benefits computed separately for each year. The slight difference is, however, more than offset by an important consideration in programming the accelerated program, namely that projects will most likely be scheduled in the order of their importance as measured by the return of benefits to traffic. Thus projects with large traffic volumes and, which after their completion will return the greatest benefits to users, are most likely to be scheduled early in the program, resulting in greater benefits during the first 10-year period than if projects were built on a random schedule with no regard for the early completion of high priority projects.

The benefits in the second and third 10-year periods were computed using the computed traffic volumes for each year based on the expansion factor for that year assuming a 4 percent annual increase in traffic each year over the 30-year period. For the second and third 10-year periods, therefore, the full user benefits were assigned on the basis of a fully completed Interstate System built during the first 10-year period. The traffic volumes on the rural and urban portions of the System and the user benefits were computed for each year instead of using the averaging procedure adopted in computing user benefits for the first 10-year period.

In Table 6 are listed the computed interest charges and the principal required to pay for a completed Interstate System in California constructed over a 10-year period. It is assumed for the purpose of this analysis that

30-year serial bonds will be used with interest at 3 percent. In comparing the user benefits given in Table 5 with the investment costs in Table 6, it is interesting to note that the user benefits during the first 10-year period are large enough to pay off all the interest charges for 30 years for the entire investment of $2,321,553,000. The benefits during the first and second 10-year periods from 1956 to 1975 are large enough to pay for both the interest and principal and leave a balance of almost one-half billion dollars. Finally, over a 30-year period corresponding to the life of the bonds, the ratio of benefits to costs is 2.3 to 1. This clearly indicates the economic justification for the early completion of the Interstate System in California.

TABLE 6 — COMPUTED COSTS FOR THE CALIFORNIA INTERSTATE SYSTEM USING 30-YEAR SERIAL BONDS WITH INTEREST AT 3%
(Construction Period 1956-1965)

Part of System	Total Interest for 30 Years	Total Principal	Total Interest plus Principal
Rural	$ 275,430,000	$ 592,318,000	$ 867,748,000
Urban	$ 804,100,000	$1,729,235,000	$2,533,335,000
Total System	$1,079,530,000	$2,321,553,000	$3,401,083,000

BENEFIT COST RATIO ON 30-YEAR BASIS = 2.3

Of greatest concern to highway engineers is the urban portion of the System where the average cost per mile is estimated at $7,044,000, as compared with $355,200 per mile for the rural portion. This study indicates that over a 30-year period the benefits on the urban portion exceed the cost by over $3 billion. This large margin of benefits over cost is even more significant when it is recognized that more than $1 billion of the cost of the Urban Interstate System is for right of way. It is questionable if this part of the cost of the Interstate System should be amortized in 30 years, since it represents value of property which is not likely to be depreciated with time but may retain its investment value or purchase price in perpetuity.

In conclusion, it may be stated that the above analysis of user benefits on the Interstate System in California provides substantial evidence concerning the soundness of President Eisenhower's proposal for an accelerated program for the construction of the Interstate System and the use of Federal funds to bring about its early completion. Furthermore, it should be recognized that the benefits will be shared not only by the highway users but also by all the people of the Nation, who make use of all the goods and services which can be more effectively and economically provided as a result of better highways. There are, however, many government agencies competing for public funds and for this reason the analysis of highway user benefits should be refined and should be supplemented by as much additional information as can be obtained concerning items which should be included in a comprehensive economic analysis of the major public works projects. The adoption of such a procedure should permit making an appraisal and evaluation of competing public works projects to provide for the most effective use of the nation's resources and for the promotion of the general welfare of all of the people of the Nation.

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Discussion of
"DETERMINING THE REQUIRED THICKNESS OF CONCRETE PAVEMENTS FOR HIGHWAYS"

by Joseph Herbert Moore
(Proc. Sep. 596)

JOSEPH HERBERT MOORE,[1] A.M. ASCE.—The writer wishes to thank the gentlemen who have contributed discussions of the original paper. The choice of the thickness of pavement has been treated much too lightly by those who have been designing highways, and yet to the layman an early failure of the pavement represents very poor engineering practice. As all of the discussions indicated, there are many variables entering into a realistic approach to the solution of this problem, and this could account for the practice of many states to simply use a standard thickness at all sites. Obviously, this is poor practice and provides no real cost comparison between the use of rigid and flexible pavements.

One of the variables on which we have little research is the fatigue property of pavement slabs. The only available data with which the writer is acquainted is that used by R. D. Bradberry and also by the Portland Cement Association; and this data is based on tests of beams. A slab without doubt deflects and rebounds in a much different manner than a beam, and as Mr. Palmer indicates, the recovery period is relatively long in the case of an actual pavement slab.

The previously unpublished data which Mr. Sutherland has furnished on measured warping stresses in 15-foot slabs is greatly appreciated and certainly provides fuel for constructive thinking. The comparison of measured and computed warping stresses in 15-foot slabs is not as disturbing as it may at first appear since these calculated stresses increase at a rapid rate and are difficult to compute for slabs from 10 to 25 feet long; beyond this length the calculated values are almost constant. Reports on the Arlington tests(1) did include comparisons of edge warping stresses along the sides of 10 and 20-foot slabs and the stresses along the 10-foot sides were almost 90% less than those along the 20-foot sides. Since the cost of the complex dowel arrangements needed at transverse joints cannot and is not ignored, today there is a tendency to use less joints and slabs of greater lengths. Therefore, the irregularities in warping computations for short slabs is not of practical importance.

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1. Bridge Engr., Joseph K. Knoerle & Assocs., Chicago, Ill.

As Mr. Harwood indicates, some of the material in the writer's paper was published in a report issued by the Joint State Government Commission of the Commonwealth of Pennsylvania. As stated in the original paper, the writer prepared the material for that report while employed by the private research firm of Haller, Raymond, and Brown. The pros and cons of rigid pavements versus flexible pavements was not an issue in the report or the author's paper; in the paper, an attempt was simply made to explain the cause of the numerous transverse cracks which tend to make concrete pavements rough and lead to high maintenance costs.

Obviously, the complexity of any realistic treatment of pavement design necessitates an engineering analysis of numerous variables, and an engineer's judgment and decision on simplifying any one of these variables is open to criticism and justly so. Design methods proposed by the writer are not purely theoretical but include a factor which represents the observed condition of many pavements in use throughout Pennsylvania. One purpose in presenting Table 9 in the original paper was to show the absurd values one could occasionally arrive at if he used either the proposed longitudinal-edge loading method or the more publicized and simpler corner loading method. However, for normal cases Table 9 clearly reveals that if the repetitions of corner loadings are realistically computed, i.e. effect of lane width is considered, our highway pavements will develop numerous transverse cracks long before any corner cracks appear. As cracks appear the seepage of water into the subgrade reduces the supporting value of the subgrade and this soon produces pavement roughness, which is a more proper measurement of pavement life. Thus, it appears to this writer that there is a definite relationship between early pavement cracks and pavement life; at least the field studies in Pennsylvania support this statement.

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Discussion of
"FLOOD-EROSION PROTECTION FOR HIGHWAY FILLS"

by C. J. Posey
(Proc. Sep. 783)

GERARD H. MATTHES,[1] HON. M. ASCE.—The experiments described in this paper demonstrate the practicability of protecting earth embankments against erosion by flowing water by means of "rock sausages," and recall the effective use that has been made of this method in foreign lands for the protection of river banks against erosion by high-velocity flow. The author is to be commended for having made full-scale experiments on an unregulated river. His findings should be of timely interest in view of this year's extraordinary toll of flood damage caused by streams too small to warrant the construction of flood control reservoirs by the Corps of Engineers, U. S. Army, under existing National flood control laws. Much can be accomplished, however, through State and local effort by employing the "rock-sausage" method of protecting highway fills and the river banks of the smaller streams, as shown by European practice covering half a century.

Wire-bound rock sausages, or gabions, originally were introduced and patented by the Italian engineer Serrazanetti,(10) about 1903, and have been extensively used along head-water streams in Italy, Austria and Bavaria since 1908. European methods of applying rock sausages along earth fills or stream banks have included (a) horizontal tiers backed by boulders; (b) vertical walls built by standing sausages on end, with cross sections square instead of round; (c) formation of dikes supported on layers of large boulders, or on fascine mattresses; (d) rock sausages sunk in sandy river beds to serve as foundations for rock fills, or (e) for sandbag cofferdams. In the United States, rock sausages have been used by the National Park Service to counteract bed erosion;(11) and by the California Highway Commission to protect the banks of streams near Los Angeles, Calif.(12) An exhaustive investigation of the uses of rock sausages in Germany and Austria was made by Dr. Eng'r Chr. Keutner in 1934.(13)

The limitations of protection provided by rock sausages as commonly cited are (a) maintenance cost, covering inspection and repairs needed after each major flood; (b) eventual break-down of the galvanized wire netting by rusting at points where abrasion by boulders or by careless handling has been suffered. Repairs usually are made by patching with strips of new netting. In the Bavarian system first cost was distributed as follows, as reported by Keutner:(13)

1. Wire netting, hexagonal mesh 32.5%
2. Providing broken stone incl. transportation, filling, sawing and placing 56.5%
3. Wear and tear of equipment, and miscellaneous . . 11.0%

Comparative costs of wires having equal strength and of dia. 2.8 and 3.0 mm showed steel wire to cost 2.4 times ordinary galvanized iron wire.

1. Cons. Hydr. Engr., New York, N. Y.

Diameter of hexagonal mesh was 60 mm (2 3/8 inch). Loss of weight of wire due to abrasion showed steel wire to lose but one-fifth as much as galvanized iron wire.

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E. W. LANE,[2] M. ASCE.—Professor Posey's paper gives, so far as the writer knows, the first report on scientific tests of the value of the "rock sausages." It should serve to bring more widely into use this very effective device for bank protection, and therefore is a valuable addition to hydraulic and highway engineering literature.

Although these "sausages" have come into use comparatively recently in this country, they have long been used in China for stream bank and bed protection, and also more recently for the closure of levee breaches along the Yellow River. Their use in the operation of the great Min River irrigation system was described by the writer in Civil Engineering in 1931.[3] This great project, which irrigates 950,000 acres of land, has been in continuous rise since about 200 B.C., and the sausages have no doubt been used for centuries. They are employed for the protection of the stream bed at a structure for dividing the flow of the Min River, and as pavement on a sort of spillway. Thin strips of bamboo are woven to form the casing of the "sausage." Similar construction was employed to form the ones used on the Yellow River. These were large and long, and were rolled into the gap in the levee from the banks, the gap being gradually closed by filling it with the sausages placed in this manner.

Soon after the above mentioned article was published, the writer received a letter from an attorney for Los Angeles County, asking if he could give a reference to any publication containing a description of these devices which was available in a library in this country a few years before, when a patent for them was given by the U. S. Patent Office. The County was being sued by the owner of this patent for a large sum because of their use of this device, which had been used for centuries in China. If such publication could be found, the patent could be invalidated.

CARL F. IZZARD,[4] A.M. ASCE, and JOSEPH N. BRADLEY,[5] M. ASCE.—

2. Hydr. Engr., Fort Collins, Colo.
3. Great Min River Irrigation Project. - E. W. Lane. Civil Engineering Vol. 1, No. 5, February 1931. pp 397-400.
4. Chief, Hydr. Research Branch, Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C.
5. Hydr. Engr., Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C.

Professor Posey and associates are to be commended on the intensive and valuable study performed on erosion protection for highway fills, which is especially appropriate at this time prior to what appears a tremendously expanded highway program. The design of highway fills to be overtopped during floods has not been unusual practice in the past, especially on secondary roads. On the other hand, current trends tend to discourage the design of river crossings which provide for overtopping of highway embankments. It may prove wise to weigh the merits of the old concept against the apparent advantages to be gained by keeping embankments above high water before going overboard in the opposite direction.

With the advent of the modern turnpike and multilane divided highway, with long sweeping curves and adequate sight distance, bridges assume a permanent role and can no longer be considered a short-term investment. This being the case, bridges on modern highways should be designed to accommodate extreme floods without failure or serious damage. Considering the inadequacy of long-range hydrologic records on most streams in the United States, elevated road embankments would make it necessary to span practically the entire flood plain as well as the stream to be reasonably sure that a bridge would be safe during the superflood. To do so would result in long, expensive bridges which would certainly be subject to severe criticism from those who bear the cost.

Records show innumerable cases where old bridges have withstood record floods while newer and more modern ones, both upstream and downstream, have failed. It behooves us therefore to reexamine and understand the act of Providence or the underlying principles which protected these old structures against nature's onslaughts.

Old bridges, built to accommodate floods with recurrence intervals of ten to twenty years, have remained intact because approach embankments were low, allowing flood waters to spill over the road for discharges greater than the capacity of the bridge proper. Many bridges filling this description have been inundated time after time while great quantities of debris have lodged against the superstructure without serious damage. There are also instances where the approach embankments to these same bridges were elevated later and the old bridge replaced by a modern one of approximately the same length with the result that the new bridge failed during the first sizable flood. With embankments raised it was necessary for all flow to pass under the new bridge, increasing the former backwater and the velocity. Failure usually resulted from undermined footings of abutments and piers.

An explanation of the hydraulic principles involved is best illustrated by an actual case on which reliable observations and measurements are available. The bridge shown in Figure 1 has withstood several severe floods, one with recurrence interval exceeding one hundred years. The bridge is 175 ft. long with sagged approaches on each side totalling a distance of about 7500 ft. The highway grade is denoted by the dash line located at elevation 70. Records indicate that the capacity of the bridge proper is about 10,000 cfs. while a flood of 26,000 cfs. or approximately two and one-half times that amount, was accommodated at the crossing with no damage to the bridge. Minor repairs were required to the downstream shoulders of the embankment.

Designers have realized some of the advantages inherent in the sagged approach design but it is doubtful whether the full significance has been comprehended. In fact, without the information gained from recent model studies it would not be possible to fully analyze the action.

The lower curve on Figure 2 represents the stage discharge relation for the river upstream from the bridge. Note that discharges up to 10,000 cfs. were carried under the bridge. As the stage reached elevation 70, flow commenced to spill over the road. With flow over the roadway, resistance decreased resulting in a corresponding reduction in both backwater upstream from the bridge and differential head across the embankment. In turn, reduction in backwater caused the flow under the bridge to decrease. By the time the stage reached elevation 75, water flowed five feet deep over the roadway while flow under the bridge fell to less than 2,000 cfs. Flow over the embankment at this point reached 24,000 cfs.

Figure 3 shows the backwater upstream for both flow under the bridge and over the roadway while the accompanying sketches illustrate the change in water surface profile. The backwater, $h_{\ddagger}$, reached a maximum of 0.37 ft. for the stage at elevation 70. The differential head, Δh^*, was slightly larger than the backwater at elevation 70 but fell to 0.015 foot as the stage reached elevation 75.

The mean velocity under the bridge and over the roadway relative to river stage is shown on Figure 4. The highest mean velocity attained under the bridge was 4 feet per second at approximately elevation 70, decreasing to 0.7 foot per second as the stage approached elevation 75. The velocity over the roadway reached a maximum of about 2 feet per second at elevation 70.3, decreasing to approximately 0.7 foot per second for river stage at elevation 75.

The greatest test withstood by the bridge and foundations occurred, therefore, not at the peak flow, but at 10,000 cfs. For flows greater than this amount the discharge and velocity under the bridge decreased. The greatest threat to the bridge at the peak of the flood was caused by timber and debris lodging against the superstructure. With the low velocities prevailing even this was not serious. The dotted lines on Figures 3 and 4 indicate the backwater and velocity, respectively, which the bridge would have been subjected to were the embankments raised sufficiently to force the entire flow under the bridge.

A contributing factor, hitherto unmentioned, is the almost unbelievable capacity of the roadway when operating as a submerged broadcrested weir. This was not demonstrated to advantage in the above example as only 3.3 cfs. per lineal foot flowed over the roadway. To illustrate this point more clearly let us investigate the capacity of the same roadway acting as a spillway with five feet of head upstream and without downstream submergence. Assuming a coefficient of 3.0 the discharge over the roadway would be

$$Q = CLH^{3/2} \text{ or } 3.0 \times 7500 \times 5^{3/2} = 252{,}000 \text{ cfs.}$$

Now suppose the same upstream conditions prevail but the downstream water level is 4.75 feet above the road grade, which would constitute a submergence of 95 percent. The coefficient of discharge for this condition, according to the most recent work on the subject,(1) would be 3.0 x 0.73 = 2.20. The discharge for the submerged condition would then be

$$Q = 2.2 \times 7500 \times 5^{3/2} = 185{,}000 \text{ cfs.}$$

Thus with 95 percent submergence, the roadway acting as a spillway would carry approximately three-fourths that for the free flow condition. This is a remarkable characteristic of the submerged broad crested weir which should certainly be used to advantage in bridge design.

Summing up the foregoing remarks, the sagged roadway in connection with bridge design has the following points of merit:

1) The bridge waterway and foundations in many cases can be designed for a moderate flood rather than an extreme one, with considerable saving in initial cost.
2) Backwater will be reduced materially once flow over the road is established. This is a very important consideration when portions of nearby towns are situated on the flood plain.
3) With the reduction in velocity the peak flow loads placed on the bridge superstructure by floating debris will be lessened.
4) A saving can be effected in the cost of the sagged roadway embankments.
5) Should hydrologic calculations be inadequately in error, loads placed on the bridge by floods of unforeseen magnitude will not be materially altered.
6) Safety of the motorist is all important. Water standing over the roadway forms its own barricade but an unbarricaded washed-out bridge is much more dangerous.

The principal disadvantage to be weighed against the above is occasional interruption of traffic with the resulting problems this may create.

Up to this point the discussion has concerned secondary roads. The sagged roadway design need not be limited to secondary roads, but should be used to advantage on the most modern interstate highways. The difference in concept between the secondary road and the modern highway lies only in the period of time allowed between inundations of the sagged portion of the roadway. Where the bridge on the secondary road had a capacity for a ten-year flood, the bridge on the modern highway may be designed for a fifty-year flood. In the first case, flow over the road would occur on an average of ten times in one hundred years while in the second case it would occur only twice in the same period. The fruit of recent research now makes it possible to design economical and safe river crossings, where moderately wide flood plains are involved, on a scientific basis.

The writers have attempted to show that neither the low nor high approach embankment is entirely satisfactory for present-day bridge design on primary roads. As stated before, the principal objection to bridge design with low embankments is interruption of traffic while that of high embankments is cost. A compromise between the two should result in a design which retains all of the advantages of the first, to a reduced degree, while favoring economy in the second. Bridge length would be selected for a given crossing by comparing cost of initial investment, plus general maintenance, plus damage to bridge and embankments, plus damage upstream by backwater, plus interruption of traffic, plus amortization, etc. for several schemes. Scientific design along these lines will result in safer bridges and at the same time permit the highway dollar to go farther.

From the above reasoning, the information presented by Mr. Posey on flood-erosion protection is directly in line with current thinking in regard to bridge design on wide and reasonably wide flood plains. Information on low-cost embankment protection will undoubtedly be in demand. Therefore

further research on the subject is to be encouraged, preferably coupled with prototype verification whenever possible. This should stress simplicity of placement, permanence, and low cost.

Another phase of research in connection with embankment protection might be the fuse-plug design mentioned by Mr. Posey. In this case it is desirable to sacrifice a section of roadway embankment to save the bridge during extreme floods. Heavy protection would be provided adjacent to but omitted at the plug. With present earth-moving equipment the time required for replacing a section of roadway embankment is measured in days compared to months for rebuilding or repairing damage to a bridge, thus if one must be sacrificed the decision should not be a difficult one.

REFERENCE

1. Sigurdsson, Gunnar—"Discharge Characteristics of an Embankment-shaped Weir." M. S. Thesis Georgia Institute of Technology, Atlanta, Georgia, June 1955.

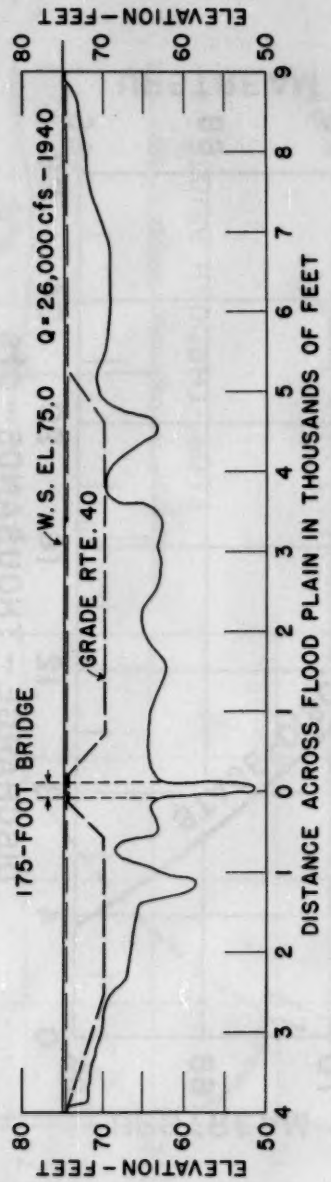
ELEVATION - FEET
80
70
60
50
175-FOOT BRIDGE
W.S. EL. 75.0 Q = 26,000 cfs - 1940
GRADE RTE. 40
4 3 2 1 0 1 2 3 4 5 6 7 8 9
DISTANCE ACROSS FLOOD PLAIN IN THOUSANDS OF FEET

FIG. 1 - FLOOD PLAIN, BRIDGE AND ROAD GRADE.

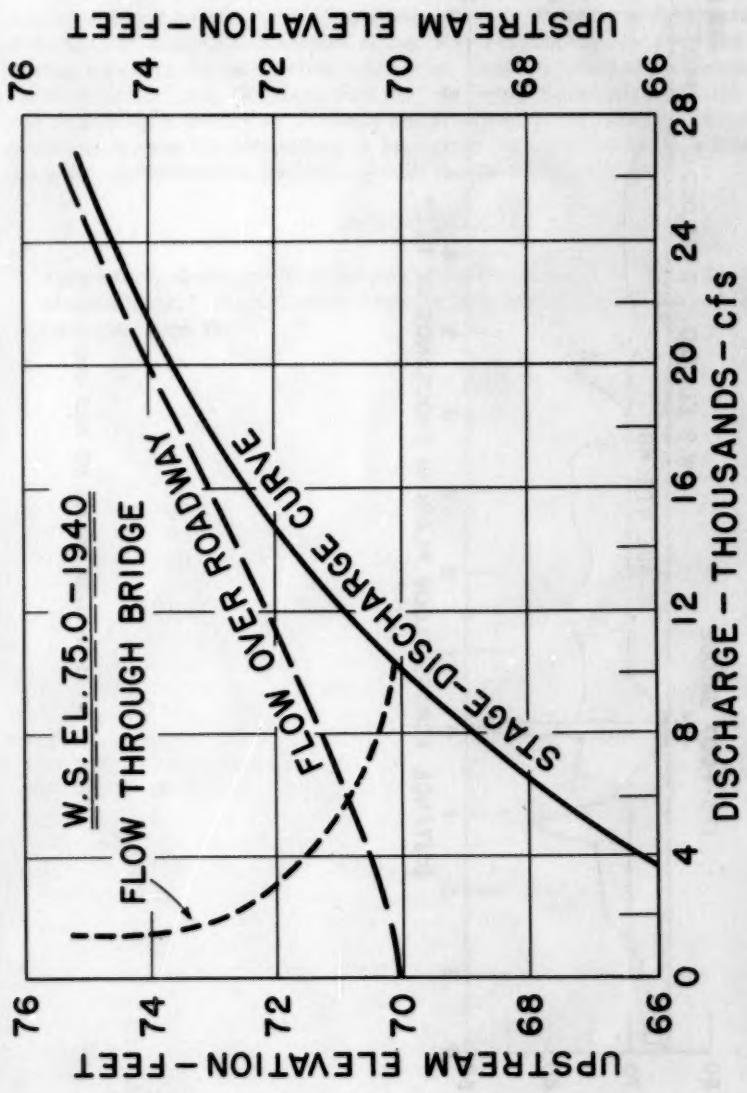

FIG. 2 - STAGE DISCHARGE RELATION.

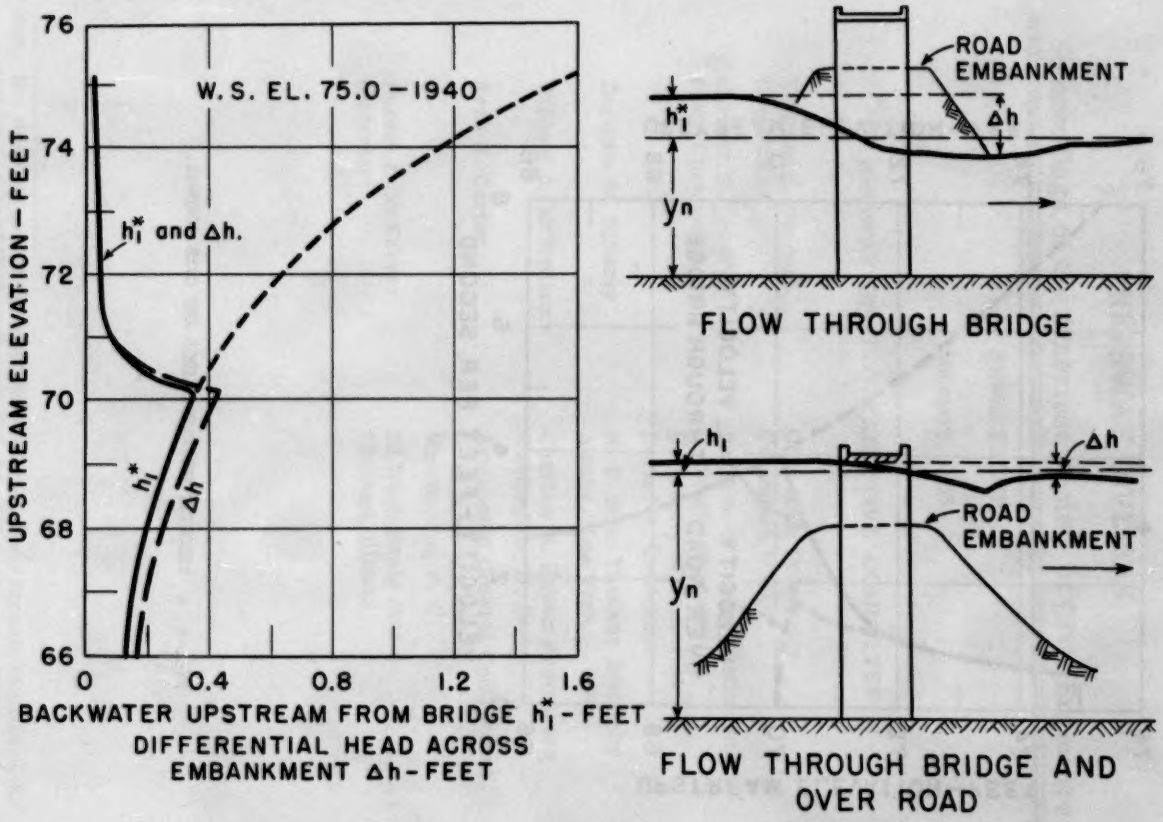

FIG. 3 - BACKWATER AND DIFFERENTIAL HEAD.

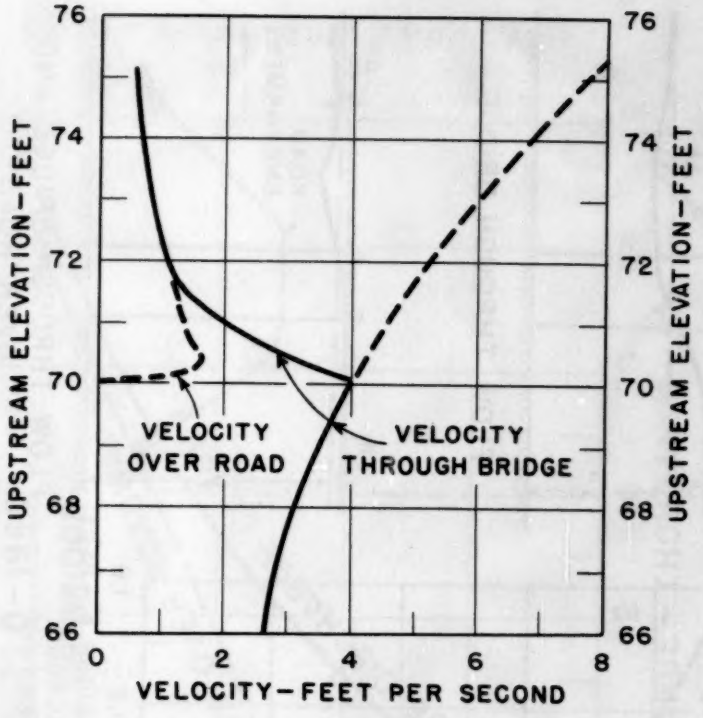

FIG. 4 - VELOCITY THROUGH BRIDGE AND OVER ROADWAY.

DIVISION ACTIVITIES

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

NEWSLETTER

January, 1956

HIGHWAY DIVISION EXECUTIVE COMMITTEE

Emmett H. Karrer[1] (Chairman)	Ohio State University Columbus, Ohio
Harmer E. Davis[2] (Vice Chairman)	Institute of Transportation and Traffic Engineering University of California Berkeley, California
Bertram D. Tallamy	N. Y. State Thruway Authority Albany, New York
William A. McWilliams	Charles M. Upham Associates Washington, D. C.
Arch N. Carter	Associated General Contractors of America, Inc. Washington, D. C.
Harold J. McKeever (Secretary)	22 West Maple Street Chicago, Illinois

Note: No. 1956-2 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 82, HW 1, January, 1956.

1. Appointed to fill unexpired term of Harold J. McKeever.
2. Appointed to fill unexpired term of George W. Deibler.

HIGHWAY DIVISION

January, 1956

Purpose: (a) the advancement of the science of civil engineering as related to the administration, economics, planning, design, construction, operation, and maintenance of civil and military highways; and (b) the professional improvement of civil engineers interested in highway and related work. The division works toward these objectives by (1) presentation and discussion of papers at Society meetings and in Society publications; (2) by appointment of committees to study and report upon particular subjects; (3) promoting highway engineering education; and (4) cooperation with other organizations engaged in similar or related activities.

NEWSLETTER

The Executive Committee of the Division has decided that the Newsletter will be published three times a year. An issue will be distributed during the month preceding each of the three National Meetings of the Society, thereby providing advance information of the planned Highway Division sessions.

Members of the Division are urged to forward to the editor items appropriate for publication in the Newsletter.

WINTER MEETING

Dallas, February 13-17, 1956

Randle B. Alexander, of the Committee on Session Programs, is making the arrangements for the Highway Division sessions at the Winter Meeting of the Society to be held at the Baker Hotel in Dallas. Mr. Alexander, who is Bridge Engineer for the Texas Highway Department, has assembled what promises to be a very interesting series of session programs.

The opening session, to be held on Thursday morning, February 15, will be a joint session with the Structural Division. Mr. Alexander and Phil M. Ferguson, of the Committee on Session Programs of the Structural Division, will preside. Speakers and subjects will be:

"The Design of the High Level Bridge Across the Corpus Christi Ship Channel"
Pat W. Clark, Bridge Engineer, Lockwood and Andrews, Consulting Engineers (formerly Special Bridge Design Engineer, Texas Highway Department.)

"The Reconstruction of the International Bridge at Laredo,"
Bengt. Sonesson, Resident Engineer, City of Laredo, Texas, and
Fred E. Koebel, Vice President and Chief Engineer of Prestressing, Inc.

"Dynamic Stress and Vibration in Two Continuous Plate Girder Bridges"
Roy C. Edgerton, Associate Member, ASCE, Research Engineer, Oregon State Highway Department.

"Progress Report of the Committee on Deflection Limitations of Bridges"
George S. Vincent, Member, ASCE, Bridge Engineer, Physical Research Branch, Bureau of Public Roads.

At the Highway Division luncheon to be held at Thursday noontime, D. C. Greer, State Highway Engineer, Texas Highway Department, will be toastmaster. J. C. Dingwall, Manager and Executive Secretary, Texas Toll Road Authority, will speak on the subject of "Right-of-Way Acquisition for Dallas-Fort Worth Toll Road."

Emmett H. Karrer, Chairman, Executive Committee, Highway Division, will preside at the Thursday afternoon session. Speakers and subjects will be:

"The Purpose of Expressways"
Frank S. Craig, Junior Member, ASCE, Expressway Engineer, Texas Highway Department, Wichita Falls, Texas.

"Foreign Operations of the Bureau of Public Roads"
A. C. Taylor, Member, ASCE, Division Engineer, Bureau of Public Roads.

"Functions and Aims of the Texas Transportation Institute"
Fred Benson, Associate Member, ASCE, Executive Officer, Texas Transportation Institute, College Station, Texas.

"Concrete Pavement, Concrete Overlay"
A. L. Chollar, Associate Member, ASCE, Supervising Field Engineer, Texas Highway Department.

ANNUAL MEETING

New York—October 25-28, 1955

Curtis J. Hooper, of the Committee on Session Programs, very successfully arranged the Highway Division sessions of the Annual Meeting of the Society held at the Statler Hotel in New York in October. The speakers and subjects covered at these sessions have been thoroughly reported in "Civil Engineering."

On October 27, during the Annual Meeting, the Highway Division's Executive Committee held a meeting during which reports were received from the different division committees. Highlights of these reports are given below.

ADMINISTRATIVE COMMITTEES

Committee on Highway Division Publications

Leo J. Ritter, Jr., chairman, reported that during the year this committee reviewed sixteen papers for publication in Proceedings. Of these, eight were selected and published.

Members of this committee are: Leo J. Ritter, Jr., Chairman, M. Alfred Kaerhle, D. H. Bray, Francis E. Twiss, A. W. Johnson, F. N. Wray, R. M. Schwegler.

Committee on Cooperation with Local Sections

Chairman S. E. Ridge reported on the rounding out of this committee, which now has a member from each of twelve of the Society's districts, leaving only two districts not presently represented. The appointees were assigned 50% to 4-year and 50% to 2-year terms to inaugurate a rotating membership.

The committee will disseminate to the local sections items of interest in the highway field. This will be done as such items become available. Three such transmittals have already been made: (1) The Clay report (2) A Highway Research Board study of technical personnel and Mr. A. C. Clark's article on the planning and design of the Interstate system of highways, and, (3) The President's message to Congress and the A.R.B.A. report on the highway industries' readiness to complete an expanded 10-year highway program. Information supplied to the local sections will, of course, also include a resume of the activities of other highway division committees in letter form.

The committee members will visit each local section at least once each year and indicate to the sections the interest of the highway division in their activities.

The committee will provide, either from its membership or from other available highway engineers of stature, speakers on matters of interest in the highway field.

The committee will assist the other committees of the Highway Division in their work by attempting to obtain local section participation in those activities. Preparation of articles on highways by the local section membership will be stressed.

The committee will attempt to establish a means of recognizing A.S.C.E. members who prepare articles of special value to the Highway Engineering profession or who perform outstanding service to the highway engineering profession. This would, of course, be in the form of recommending action by the Executive Committee.

Members of this committee are: Sylvester E. Ridge, Chairman, Curtis Hooper, John O. Morton, Edward J. Nunan, J. N. Clary, W. K. Beckham, Ellis Danner, S. M. Rudder, George L. Eppe, Charles C. Morris, William A. Bugge, J. L. Cheatham, Jr.

Committee on Session Programs

Curtis J. Hooper, as past chairman of highway sessions, suggested that a manual or outline be prepared defining the responsibilities and steps to be taken by all concerned planning such sessions. He emphasized the necessity of getting early headquarters clearance for sessions since there is a "first come, first served" basis of alloting convention program time to the various divisions.

Randle B. Alexander, of the Texas Highway Department, will be chairman of session programs at the Dallas meeting in February. Eldridge A. Whitehurst, director, Tennessee Highway Research Program, University of Tennessee, Knoxville, will be chairman of the Session Programs for the Society's meeting to be held in Knoxville in June, 1956. Walter T. Brooks, who was to have performed these duties, has, regrettably, resigned due to ill health.

James W. McKnight, of the Portland Cement Association, will be chairman of the Division's Session Programs at the 1956 Annual Meeting to be held in Pittsburg, in October.

TECHNICAL COMMITTEES

Committee on Developments in Highway Engineering and Construction

Arch Carter, chairman, reported that the members of this committee had prepared nine articles for use in "Civil Engineering" Magazine and that several other articles are being prepared for publication in the Society's Proceedings.

Members of this committee are: Archie N. Carter, Chairman, Wilson T. Ballard, Joseph Barnett, William N. Carey, Jr., Claude C. Coykendall, Raymond J. Hodge, Conrad H. Lang, James J. Mennis, Burton W. Marsh, Hubert E. Snyder, Richard H. Wilson, Robert J. Ratner, Bonner S. Coffman.

Committee on Significance of Tests for Highway Materials

This committee, of which Taylor Lewis is chairman, has taken important action in the past year after a considerable period of inaction. Basic reports are in preparation and due soon on three subjects: Soils, Bituminous Materials, and Aggregates. The reports may be appropriate for publishing as Separates, this to be determined by the Publication Review Committee.

Members of this Committee are: Taylor D. Lewis, Chairman, Robert F. Baker, Fred J. Benson, Ray E. Bollen, Lowell E. Gregg, George A. Rahn, Tilton E. Shelburne, Ralph E. Simpson.

Committee on Geometrics of Highway Design

Chairman Wilson T. Ballard reported that his committee had established limited objectives with respect to toll or expressway type facilities. The aim will be to develop informative data on their design and effectiveness of operation, leading to an eventual report.

Because of the scope and complexity of this subject, and the difficulty of developing the type of operational data wanted, the committee work might be confined to some one phase, such as for example, acceleration and deceleration lanes. A limited and workable committee project is to be outlined further by Mr. Ballard, and reported to the Executive Committee for approval.

Also discussed as a possible committee task is the standardization of symbols and other details found in highway construction plan sheets.

Members of this committee are: Wilson T. Ballard, Chairman, Jacob C. Young, Ralph L. Fisher, Conrad H. Lang, Donald W. Loutzenheiser.

Committee on Highway Planning and Finance

Chairman Ralph A. Moyer reported on the proceedings of the October 25 meeting of this unusually active committee. Each member had presented a formal report concerning phases of highway planning and finance as related to the committee's work.

Mr. Jorgensen discussed the objectives of the committee and the reasons which led to organizing the committee as a part of the A.S.C.E. He cited the need for a strong program in the Highway Division in view of the importance of and a need for an accelerated and coordinated national and state highway program.

Mr. Lynch reported that the 1955-1956 budgets of the Bureau of Public Roads and the State Highway Departments provided a total of $21 million for studies of highway planning and finance. Of these funds, about 42% have been spent in traffic and parking surveys and the remainder on such work as inventory, mapping, fiscal studies and research. In general, the use of origin and destination surveys and other types of highway planning studies is on the increase.

Mr. Fratar presented a report on urban highway planning and finance. He stated that planning and finance operations in large metropolitan areas have been complicated by divergent views of various jurisdictions and that there is need for developing procedures for better cooperative action.

Mr. Clarkeson pointed out the need for consistency and uniformity in freeway design standards in all states. He discussed the importance of public relations in selling freeway programs to the public. He also expressed the need for development of better procedures for determining traffic growth factors.

The chairman summarized the discussions by preparing a list of twelve topics to be reported on by committee members and others in an effort to bring in focus plans for future study and committee action.

Committee on Highway Traffic Engineering

Chairman Wilbur Smith and the others of this committee have prepared an agenda of traffic engineering problems to be investigated.

Members of this committee are: Wilbur S. Smith, Chairman, Donald M. McNeil, Burton W. Marsh, Mike H. A. Flanakin, George M. Webb.

Committee on Highway Engineering Manpower

Carl E. Fritts, present as chairman, reported on a meeting of his committee during the convention week. Principal result was the recommendation that the committee sponsor preparation of a brochure entitled "Careers in Highway Engineering" for wide distribution among young men in high schools. The Executive Committee approved this recommendation and requested the Manpower Committee to develop a more complete plan of action for the preparation and distribution of such a booklet.

Efforts are being made to have published the excellent papers presented by the members of this committee at the Highway Engineering Manpower Symposium, either in "Civil Engineering" or as Proceedings Separates.

Members of this committee are: Carl E. Fritts, Chairman, Dwight H. Bray, Harmer E. Davis, Harold G. Sours, Robley Winfrey.

Committee on Federal Highway Legislation

This committee is expected to be formed for supplying data on highway needs and recommended policies to Congressional committees, in the furtherance of sound federal legislation for an accelerated national highway program. It is understood, however, that initial action in this respect will come from the Society Board with none expected presently from the Highway Division.

Newsletter Editor: George H. Leland
Edwards, Kelcey and Beck
3 William Street
Newark 2, New Jersey

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 861 is identified as 861 (SM1) which indicates that the paper is contained in issue 1 of the Journal of the Soil Mechanics and Foundations Division.

VOLUME 81 (1955)

JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)[c], 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)[c], 596(HW), 597(HW), 598(HW)[c], 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)[c], 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)[c], 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

JUNE: 702(HW), 703(HW), 704(HW)[c], 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)[c], 710(CP), 711(CP), 712(CP), 713(CP)[c], 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)[c], 719(HY)[c], 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)[c], 727(WW), 728(IR), 729(IR), 730(SU)[c], 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)[c], 749(SA), 750(SA), 751(SA), 752(SA)[c], 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)[c], 759(SM)[c], 760(WW)[c].

AUGUST: 761(BD), 762(ST), 763(ST), 764(ST), 765(ST)[c], 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(EM), 773(SA), 774(EM), 775(EM), 776(EM)[c], 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)[c], 783(HW), 784(HW), 785(CP), 786(ST).

SEPTEMBER: 787(PO), 788(IR), 789(HY), 790(HY), 791(HY), 792(HY), 793(HY), 794(HY)[c], 795(EM), 796(EM), 797(EM), 798(EM), 799(EM)[c], 800(WW), 801(WW), 802(WW), 803(WW), 804(WW), 805(WW), 806(HY), 807(PO)[c], 808(IR)[c].

OCTOBER: 809(ST), 810(HW)[c], 811(ST), 812(ST)[c], 813(ST)[c], 814(EM), 815(EM), 816(EM), 817(EM), 818(EM), 819(EM)[c], 820(SA), 821(SA), 822(SA)[c], 823(HW), 824(HW).

NOVEMBER: 825(ST), 826(HY), 827(ST), 828(ST), 829(ST), 830(ST), 831(ST)[c], 832(CP), 833(CP), 834(CP), 835(CP)[c], 836(HY), 837(HY), 838(HY), 839(HY), 840(HY), 841(HY)[c].

DECEMBER: 842(SM), 843(SM)[c], 844(SU), 845(SU)[c], 846(SA), 847(SA), 848(SA)[c], 849(ST)[c], 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)[c], 857(SU), 858(BD), 859(BD), 860(BD).

VOLUME 82 (1956)

JANUARY: 861(SM1), 862(SM1), 863(EM1), 864(SM1), 865(SM1), 866(SM1), 867(SM1), 868(HW1), 869(ST1), 870(EM1), 871(HW1), 872(HW1), 873(HW1), 874(HW1), 875(HW1), 876(EM1)[c], 877(HW1)[c], 878(ST1)[c].

c. Discussion of several papers, grouped by Divisions.

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